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PROJECT PIMO FINAL REPORT

PIMO TEST SUMMARY

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et al

SERENDIPITY, INC.

FOREWORD

This report (Volume I through Volume VIII) represents the final phase of a study and test which was initiated in September 1964 to explore newly developed techniques and devices for presenting T. O. (Technical Order) type instructions and information. The eight volumes of data contain the result of a test conducted in an operational environment using concepts developed during an earlier phase under Contract AF 04(694)-729 and documented in BSD-TR-65-456. Both the early phase and final phases which were accomplished under Contract AF 04(694)-984, Project 1316, "Presentation of Information for Maintenance and Operation (PIMO)", were started in June 1966 and completed in April 1969. This final report was submitted in May 1969.

The original program documentation was prepared by Mr. C. L. Schaffer, SMTE, in 1964. He subsequently functioned as the Air Force Program Director and Chairman of a Working Group which monitored all development throughout the life of the project. This Group was composed of individuals from various Air Force commands (AFLC, MAC, ATC, ADC, AFSC) and the Army Command (AMCPM, AXMLE) knowledgeable in the various maintenance disciplines and all facets of the T. O. system. Capt. Don Tetemeyer, the Project Scientist during the formulative stages of the Program was largely responsible for the basic test structure. Mr. John Saunders was the monitor for all contractual aspects until his reassignment in 1968.

Any success one may attribute to the project must be shared by numerous individuals; however, major credit and appreciation are due General Howell M. Estes, Jr., Commander of the Military Airlift Command, who provided the C-141A aircraft and the bases at Charleston, Dover and Norton for the operational test. Sharing in the credit for the MAC contributions are Lt. Col. Don Watt and his staff at Hq. MAC, and Col. Foreman, Col. Henzi, W/O Van Riper and all the personnel at Charleston Air Force Base and also at Dover and Norton who participated in the test. The hardships imposed on their organizations are recognized, and we sincerely appreciate the special efforts put forth to overcome all obstacles. The test could never have been conducted without the cooperation and competent performance of these many individuals.

We are especially indebted to the Air Force Human Resources Laboratory, Wright-Patterson Air Force Base for their financial contributions at a critical point in the project; and also to the Army Materiel Command, who believed the test potential of sufficient magnitude to warrant the expenditure of their funds. We are most grateful for their confidence and assistance. It is most assuredly the primary factor that permitted completion of the test.

This technical report has been reviewed and is approved.

D A Cook

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ABSTRACT

This report describes the latest phase in the program to develop and evaluate PIMO (Presentation of Information for Maintenance and Operation); a job guide concept applied to maintenance. Between August 1968 and April 1969, a test was conducted at Charleston AFB, South Carolina, to determine the effectiveness of PIMO. Three immediate behavioral effects were expected: 1) reduction in maintenance time, 2) reduction in maintenance errors, and 3) allow usage of inexperienced technicians with no significant penalty. Experienced and inexperienced Air Force technicians performed maintenance on C-141A aircraft using PIMO Job Guides presented in audio-visual and booklet modes. Performance was measured in terms of time to perform and procedural errors. The performance was compared with the performance on the same jobs by a control group, i.e., experienced technicians performing in the normal manner. The following conclusions were drawn from the test results: 1) after initial learning trials, both experienced and inexperienced technicians using PIMO can perform error-free maintenance within the same time as experienced technicians performing in the normal manner, 2) inexperienced technicians perform as well as experienced technicians when both use PIMO, 3) there is no significant difference between audio-visual and booklet modes, 4) the users revealed an overwhelmingly positive reaction to PIMO, and 5) the performance improvements provide the capabilities to significantly improve system performance defined in terms of departure reliability, time-in-maintenance, and operational readiness. This report also presents a description of the recommended operational system, specifications and guidelines for PIMO format development, including troubleshooting.

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SECTION I

INTRODUCTION

A. GENERAL

With the coming of age of complex weapons systems, a requirement arose for a modern, efficient presentation of technical information relating to the maintenance of those systems. Project PIMO (Presentation of Information for Maintenance and Operations) was let by the Air Force to Serendipity, Inc. to research and develop a means to satisfy this requirement. This research led to revolutionary concepts in the techniques associated with presenting maintenance information.

B. PIMO CONCEPTS

The basic concept which developed, revolved around the formatting of maintenance information. This new formatting quickly led the investigators to consider the merits of two separate modes of presentation.

1. Print Mode

The first of these modes was that of printed booklets comprised of short, simple maintenance steps and informative pictorials for each step. Technical procedures were standardized and the textual vocabulary kept at a level to ensure comprehension by the user. A highly stylized pictorial drawing technique was developed which controlled the amount of information included only to that amount absolutely necessary. (For detailed information concerning the print mode, see Volume I).

2. Audio-Visual Mode

In addition to the print mode, the maintenance information was organized and presented audio-visually. In this mode, the pictorials which were used in the booklet were presented visually, while instructions were given by voice narration. (For detailed information concerning the audio-visual mode, see Volume I).

C. PIMO EVALUATION

In order to make a valid evaluation of the relative effectiveness of the two presentation modes, a comprehensive test was required. Once the data were developed, it was necessary to measure their relative effectiveness in a realistic situation. Therefore, with Air Force approval and cooperation, a field test was constructed and implemented. In this way, PIMO concepts were to be tested on an operational aircraft maintenance system (C-141) with actual maintenance performed following PIMO procedures.

D. CONCLUSIONS

1. Test Results

The test results show that when PIMO formatted data are used, apprentices with and without specialist training can perform as well as specialists using conventional Air Force technical manuals. Furthermore, these apprentices, after repeated exposure to the same job, will perform at the same level as the highly-trained and experienced specialist performing without data. This would tend to indicate that the training for first term enlistees can be drastically reduced. They can be assigned to maintenance bases with minimal training and therefore, be productive during most of their enlistment term. Specifically, a 25.8% increase in productive utilization may be realized if just the customary O.J.T. is eliminated. An even greater increase may be realized if technical school time -- 6 months -- could be shortened. There is some evidence that the use of PIMO may allow for such a course truncation.

In the event that the technician demonstrates proficiency and willingness to remain in the service, he then can be sent to specialist training. Specialist training will still be required since the job guides cannot cover all activities. However, PIMO Job Guides will facilitate specialist performance when they are assigned to new aircraft.

2. Potential Savings

Our simulation studies using the AMES model indicate that significant improvement in such system level parameters as departure reliability, time in maintenance and operational readiness can be realized simply by using apprentices and non-specialists for what is currently reserved for specialists. Again, this potential will be realized only if the maintenance managers are willing to assign these non-specialist people to jobs which can be performed adequately by them when PIMO Job Guides are available.

In conclusion, then, it can be seen that PIMO represents: 1) an important step forward in the technique of data presentation; 2) an improved capability of aircraft maintenance; and 3) a greater productive utilization of Air Force maintenance personnel.

3. Consideration for Implementation

Many of the results of the PIMO test are quite dramatic and have considerable implications for the Air Force. These implications can be realized only if the PIMO Job Guide concept is applied properly, and the Air Force takes advantage of the potentials of the PIMO Job Guide concept. Simply delivering a set of PIMO Job Guides at a given base will not necessarily result in improved performance or cost savings.

Any organization is a system. One portion of the system cannot be changed without affecting or changing other subsystems which interact with the portion changed. It would be erroneous to assume that a change in the technical data system can be accomplished without a corresponding change in training or maintenance management concepts. This is necessary in order to take full advantage of the power of the job guides.

In evaluating the cost effectiveness of the PIMO Job Guides, one should also consider the costs involved in making the related changes. The related costs are difficult to identify at this time. However, it must be understood that if the Air Force is not willing to incur the cost of

implementing the PIMO Job Guides properly, the tremendous advantages inherent in the use of these job guides will be significantly diluted.

PIMO provides the capability for utilizing both apprentices and non-specialists for many of the jobs currently reserved for specialists, but this added capability is meaningless if the maintenance managers will not assign the non-specialists and apprentices to the jobs. In the case of a new system, the evidence indicates that PIMO will allow the technicians to conduct nearly error-free maintenance from the outset. It can be demonstrated that even with the very few changes suggested here, significant improvements can be realized for new Air Force systems.

4. Data Usage

Many argue that the technicians will use any set of data if proper "muscle" is applied. However, considerable evidence accumulated by our experience in examining maintenance by different individuals, at many different bases and for different commands, indicates otherwise. Data usage appears to be an exception rather than the rule.

Serendipity observed and reported in an earlier phase of the study that use of conventional manuals was less than 5 percent. Observations made during the current test indicated that usage continues to remain considerably less than 5 percent. A study conducted under the auspices of the Aeromedical Research Laboratory at Wright-Patterson Air Force Base, tended to verify these observations.

These results are not surprising and certainly should not be construed as a condemnation of the conventional manuals. The manuals are not designed (nor required to be designed) for use on the job. It should not be surprising, therefore, to find the manuals are, indeed, not used on the job. The extent to which the manuals are used off the job is not known. The PIMO test results indicate that technical manual requirements should now be changed so that manuals will be designed for use on the job, by both experienced and inexperienced technicians.

The technicians appear to have a very strong bias against using data on the job. In fact, we have seen at least one occasion where a crew chief refused to use a technician simply because he brought technical data along with him. There appears to be a general tendency to "look down" upon any individual who "has to use data to perform the job". During the earlier portions of PIMO, when the test was conducted at three different bases, we were operating under the strict definition of non-interference. Therefore, we could only encourage the technicians to use the data, i.e., could not require them to use it. Under these circumstances, the percentage of people who actually used the data was approximately 20 percent. Although this figure is significantly higher than the use of conventional manuals, it was still not adequate. Those exposed to the data expressed positive acceptance, but still the usage was relatively low. Part of the low usage may be attributed to the fact that only 5-levels were assigned to the jobs. Most of these technicians felt they knew the job and therefore did not need technical data. On the other hand, in the test conducted at Charleston, both usage and acceptance were significantly higher for the specialists as well as the apprentices. The difference seemed to be that in Charleston, we spend considerable time working with the technicians in an attempt to get them to overcome whatever bias existed. It also is likely that seeing the apprentices perform effectively with the PIMO guides contributed to the acceptance by the specialists. The more important point is that the specialist did accept the job guides, and it was not necessary to apply any "muscle".

It can be anticipated that if job guides are delivered to a base heretofore unfamiliar with PIMO, usage will be higher than in the case of conventional manuals, but will not be sufficiently high to realize the full potential of the guides. Therefore, it is strongly urged that a carefully developed program of orientation, training, and public relations be developed before implementation. Training should be conducted by representatives of the Air Training Command. Furthermore, there should be one representative at each base who is thoroughly familiar with the PIMO Job Guides and is a strong supporter. This person should maintain a continuous educational program with respect to PIMO and PIMO Job Guide

usage. In addition, there should be a cadre comprised of one representative from each shop for each shift. This cadre should be thoroughly trained on PIMO, so that they can answer any questions.

Thus, an intensive and systematic orientation and training program will have a significant impact in realizing the full potential of the PIMO Job Guides.

SECTION II

STATEMENT OF THE PROBLEM

A. INTRODUCTION

The basic problem addressed by PIMO stems from an "impasse" resulting from the recent proliferation of complex Air Force systems and components. This proliferation resulted in high support costs which limit the utilization of the systems.

B. DEVELOPMENT OF THE PROBLEM

One major source of the high support cost is the current concept of providing and using the maintenance manpower capabilities. With the proliferation of new components and systems, maintenance has become extremely complex. The basic means of meeting the increased maintenance demands is still one of using highly trained and experienced technicians. However, because of the increased complexity, the technicians have become specialized. This specialization limits cross-utilization of personnel, thereby increasing the total number of personnel required to support any given system. The extensive training given to the specialists (both formal and on-the-job) not only has increased the high training costs, but also has limited the utilization of these personnel in productive maintenance labor to a relatively small percentage of the first enlistment term. Furthermore, since the technicians have to receive extensive training before they can be assigned meaningful maintenance jobs, the Air Force capability to mobilize quickly during periods of emergency is also limited. In other words, the extent to which we can increase the productive maintenance manpower during periods of emergency is limited by the time we have to take to train the new technicians.

When the system complexity problem is examined in terms of the capabilities required of maintenance personnel, it is interesting to note that the complexity results primarily from the tremendous increase of information a technician has to bring to bear on any given job. Significantly,

this has not resulted in any appreciable increase in motor proficiency, vision, or hearing capabilities; rather, the maintenance jobs have become more difficult primarily because the people simply have to remember more information relevant to any given assignment.

If one accepts the assumption that information is the key to complexity, it is not surprising that the technical orders (the primary source of this information) have become the scapegoat for the basic problem. However, it does not behoove the Air Force to restrict their attention to the technical orders. The basic problem is over-reliance on highly-trained and experienced technicians to accomplish all the maintenance. Examination of the required maintenance jobs clearly indicates that many of the jobs can be accomplished by personnel with lesser training and capability than is currently designated, if the information problem can be resolved. Nonetheless, this will not necessarily result in breaking the "impasse", unless training is adjusted accordingly and personnel with lesser training and experience are, in fact, utilized.

The maintenance situation today is so complex that there is -- and probably will continue to be -- a definite need for highly-trained and experienced specialists. But, their talents should be applied to where the need truly exists as in complex troubleshooting situations, supervision, areas requiring high motor and visual proficiencies (e.g., structural repair, inspection, etc.) -- and to cover the various unpredictable events common within such complex situations. The specialist should not be burdened with jobs which can be handled by people with less training and experience. Consider the problems faced by many bases. Very few maintenance jobs are officially designated for the so-called 3-level technicians. Yet, because of personnel turnover, nearly 50 percent of the maintenance staff at a given base may be 3-level technicians. The maintenance managers are supposed to "abide by the book" and utilize only the qualified technicians for the required maintenance. This could result in a drastic reduction of aircraft readiness; therefore, in reality, they end up using the 3-level technicians simply because they have no other alternative. They pay a penalty in maintenance efficiency and reliability in many

cases, because the manpower system is not set up to utilize these personnel effectively. If the inexperienced can be assigned to meaningful maintenance jobs without a significant sacrifice in efficiency, the available manpower pool can be increased from 25 to 50 percent. This increase alone will be a great step forward in reducing the magnitude of the high support cost problem and the resultant limitation on system utilization.

The above problem is compounded by the relatively low retention of maintenance technicians. Many of the individuals who receive expensive and extensive specialist training, leave the Air Force after a first term enlistment. This means that the needed manpower resulting from this investment is lost after only one or two years of productivity.

C. PROPOSED SOLUTION

The solution to this problem can be to limit difficult maintenance jobs to highly trained and experienced technicians. A key to resolving the impasse is an information system which will reduce the complexity of the jobs by eliminating the need for technicians to remember all of the information relevant to a given task in a given job. (See Figure 2-1.) This information must be usable on the job if we hope to decrease the complexity of the job through reduction in memory requirements. This will not resolve the problem, but will simply provide the capability to resolve the problem. The problem can be resolved only if the capability is applied, and maintenance jobs are assigned to technicians with lesser training and experience on selected jobs.

Stated in another way, the basic issue is a manpower system problem. The present manpower system is not designed to take full advantage of the available manpower. And, as with any other system problem, it cannot be resolved by changing only one portion of the system, e.g., information subsystem. The interfacing portions must be changed to assure that the system is improved indeed.

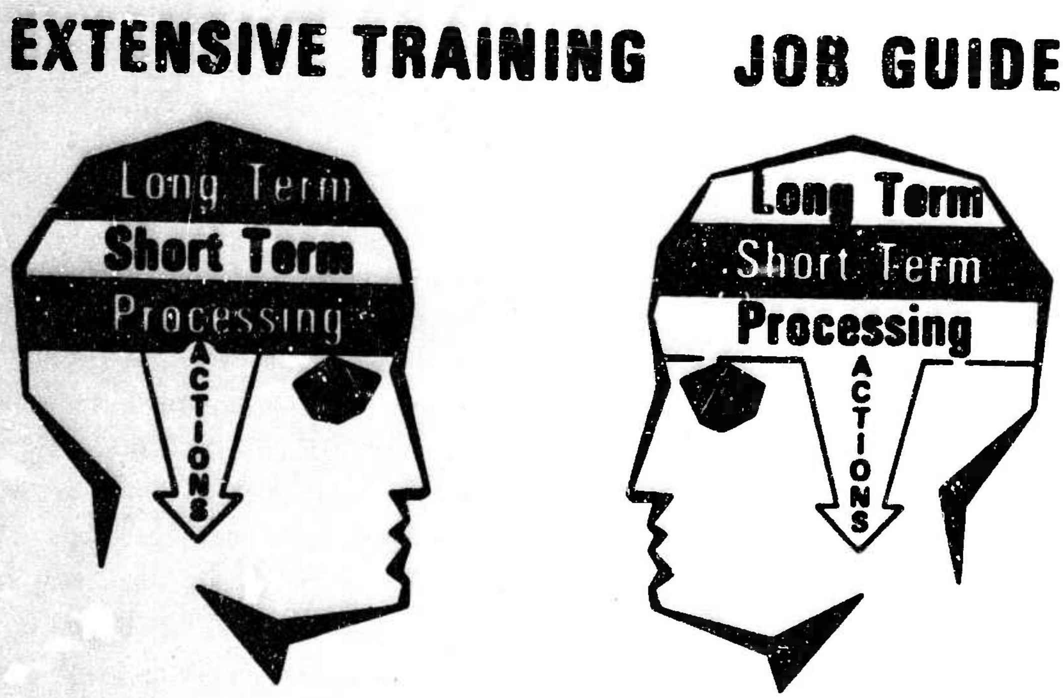

Figure 2-1. Memory requirements, training vs. job guides.

SECTION III

HISTORY OF PIMO

A. PROBLEM DEFINITION

In 1964, the United States Air Force began a concentrated effort to analyze mounting problems associated with the newer, more complex and more sophisticated military aircraft systems. One area of investigation which seemed potentially able to yield significant returns was that of aircraft maintenance. It was discovered that the standard Air Force technical orders, the vehicle used to present information to the maintenance technicians, had gone without significant change for the last thirty years. These technical orders were originally designed for the experienced specialist, and justifiably so. However, the rapid increase in techniques for information presentation seemed to indicate that these new techniques could be applied to the modernization of the technical orders with some real benefits. For example: technical orders denied the maintenance base the ability to use apprentice technicians. It seemed to follow logically, that through changes in tech data, lower skill level personnel could be used, thereby freeing the experienced technician for more complex jobs and increasing the population of competent maintenance technicians.

While the problem of technical data modernization was not the only one investigated by the Air Force at this time, it is from that area specifically that this project grew. Therefore, in that same year, Lieutenant General W. A. Davis, Vice Commander, AFSC, initiated a working group with the specific assignment to study ways in which the technical order system could be improved. This group was composed of members from all major Air Force agencies, plus members from the other services. The group was charged with the responsibility to 1) develop a work statement, 2) issue an RFP, and 3) monitor the subsequent contract.

In 1965, two contracts were let (see Figure 3-1). The first, issued to Serendipity, Inc., was to study the effects of improved job guides on the UH-1F Helicopter system. The second was let to R. M. Parsons Company to perform a similar study on the BUIC-416M (Back Up Interceptor Control) system. The conclusions drawn from these studies emphasized the need for the application of job guide concepts, and for the generation of improved techniques of information formatting. Serendipity, through both basic and applied research, developed what seemed to be a workable, new formatting technique. Moreover, there was some indication that perhaps two modes of information presentation warranted testing. The first -- print mode -- was comprised of the newly formatted maintenance instructions. This new print format stressed simplicity in text and illustration. The second, a somewhat more sophisticated mode, employed audio-visual presentation. It was intended that this technique be capable of presenting maintenance instructions on-board aircraft by displaying the pictorial (as developed for the print mode) visually, while presenting the textual material with voice narration.

B. PILOT TESTING

The new concepts, under the acronym PIMO (Presentation of Information for Maintenance and Operations), were laboratory tested during Phase 1A of the PIMO Program. This test employed three modes of presentation: audio-visual, printed manuals (containing instructions identical to the audio-visual), and standard USAF technical orders. The test was conducted in a shop using selected components from the UH-1F Helicopter system.

The upshot of this study indicated that PIMO was indeed effective in reducing maintenance times and errors, and that the concept warranted further study. Results of the Phase 1A test were presented to the Air Staff, who then decided to initiate Phase 1B. This phase, again awarded to Serendipity for study, revolved around a small feasibility study in which PIMO concepts were applied to the C-141A maintenance program.

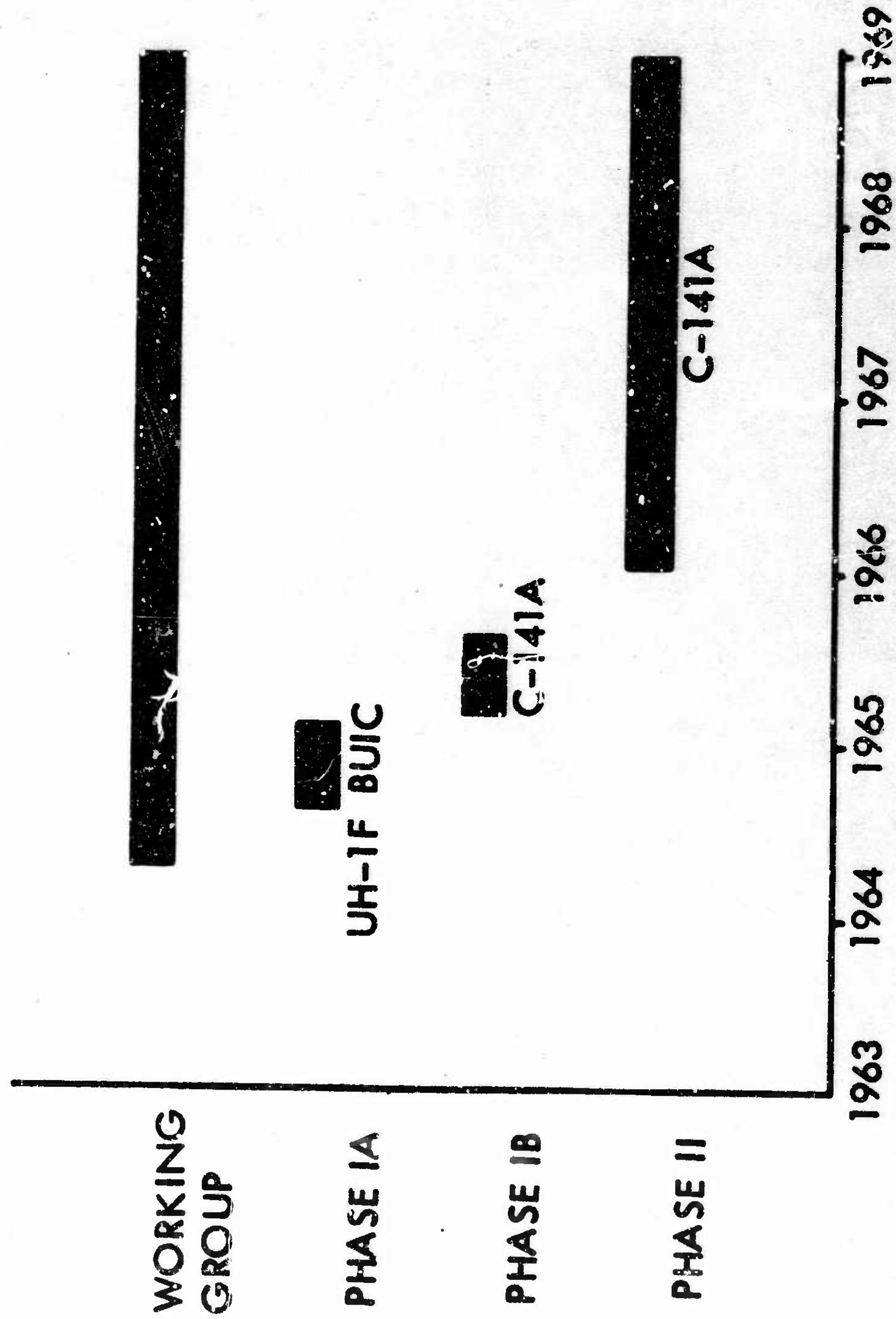

Figure 3-1. PIMO project history.

The conclusions of Phase 1B indicated that a significant savings in manpower and money could be experienced if the PIMO concepts were adopted. But a final comprehensive and exhaustive field test was called for in order to gain a substantial validation of the general and specific effects of PIMO on a system-wide basis. That study was conducted during 1967-69 at Charleston, Dover and Norton Air Force Bases. The results of this final study demonstrated conclusively that significant improvements in over-all system effectiveness can be realized through the utilization of PIMO Job Guides.

SECTION IV

PIMO FIELD TEST DESIGN AND IMPLEMENTATION

A. INTRODUCTION

Since the field tests associated with the earlier phases of the PIMO program have been reported elsewhere, and since the last field test is the natural extension and culmination of all previous effort, this section will be devoted to the description of that last test.

The subject test was conducted at Charleston Air Force Base, South Carolina, between August 1968 and March 1969. Two full-time Serendipity, Inc. representatives were stationed at Charleston throughout this period, and were supplemented as required by other Serendipity staff members.

B. FIELD TEST DESIGN

1. Objectives

The goal of the PIMO field test was to permit an objective assessment of the PIMO concept on aircraft maintenance and subsequent aircraft system effectiveness. Earlier studies concerned with the use and effectiveness of the PIMO concept -- when applied to helicopter maintenance -- led to the generation of five specific hypotheses. These hypotheses stated that, through the use of PIMO formatted data:

a. A decrease in maintenance time of at least 10 percent would be experienced.

b. PIMO data presented via audio-visual mode would result in an additional 10 percent reduction in maintenance man-hours.

c. A 45 percent reduction of maintenance errors would be possible when technicians use PIMO Job Guides.

d. For 80 percent of the maintenance tasks which might occur, a 3-level technician with PIMO could perform as well as a 5-level technician with standard USAF technical orders.

e. A significant reduction in system-wide spares consumption would result.

Stated symbolically, these working hypotheses, together with their corresponding null hypotheses, appear in Figure 4-1. More generally, there were three immediate behavioral effects which were expected. Stated simply, these effects were:

1. Reduction in maintenance time.
2. Reduction in maintenance errors.
3. Ability of apprentice technicians to perform specialized maintenance with the use of PIMO.

The data taken during the main testing effort, in addition to being subjected to standard statistical analysis techniques, were used to provide the base for an exercise of the AMES Model. This model, described in detail in Section VII, provides for an evaluation of the effect of improvement in aircraft maintenance on over-all system effectiveness, e.g., flying hours, sorties.

In addition, a separate study -- accomplished concurrently with the main study -- was made to evaluate the effects of a set of Troubleshooting Aids (TSA's) which incorporated a series of Maintenance Dependency Charts (MDC's) for fault isolation.

Lastly, an assessment of user attitude and acceptance of PIMO was made through the use of an attitude questionnaire.

	WORKING	NULL
1.	$MMH_{+PIMO} \le .1\left(MMH_{-PIMO}\right)$	$MMH_{+PIMO} = MMH_{-PIMO}$
2.	$MMH_{A\text{-}V\ PIMO} \le .1\left(MMH_{PIMO}\right)$	$MMH_{A\text{-}V\ PIMO} = MMH_{PIMO}$
3.	$SCR_{+PIMO} < SCR_{-PIMO}$	$SCR_{+PIMO} = SCR_{-PIMO}$
4.	$3L_{+PIMO} \ge .8\left(5L_{TO}\right)$	$3L_{+PIMO} \le .8\left(5L_{TO}\right)$

KEY

MMH = MAINTENANCE MAN HOURS
A-V = AUDIO-VISUAL
+ = WITH
- = WITHOUT
SCR = SPARES CONSUMPTION RATE
3L = NUMBER OF MAINTENANCE ACTIONS PERFORMED BY 3-LEVEL
5L = NUMBER OF MAINTENANCE ACTIONS PERFORMED BY 5-LEVEL
TO = TECHNICAL ORDERS

Figure 4-1. Specific Hypotheses for PIMO Field Test

2. Experimental Design

a. General Characteristics

The experimental paradigm selected for the basic study was P x Q x R factorial design (see Figure 4-2). In this way, it would be possible to employ the analysis-of-variance model for data reduction and interpretation. It is generally accepted that the analysis of variance method -- especially suited for factorial designs -- provides a high level of confidence in subsequent inferences, allows for an inspection of interaction effects, and calls for the greatest economy of calculations.

For the analysis of the TSA evaluation study, student's t was employed rather than analysis of variance, since the paradigm would not contain as many dependent variables.

For analysis of the questionnaire data, χ^2 was originally selected, but because the data would later show such an overwhelming and unambiguous positive response, only descriptive statistics are reported.[1]

Since field tests are rarely as closely controlled as those conducted under laboratory circumstances, it was decided to accept the .05 level of confidence.

b. Specific Characteristics

1) Independent Variables -- the two main independent variables to be considered were presentation of PIMO formatted data, a) via booklets, or b) via audio-visual techniques.

In addition, four maintenance activities were selected for investigation.

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[1] For a large number of questions, for example, the distribution of responses would be, or would approximate, 100%:0%.

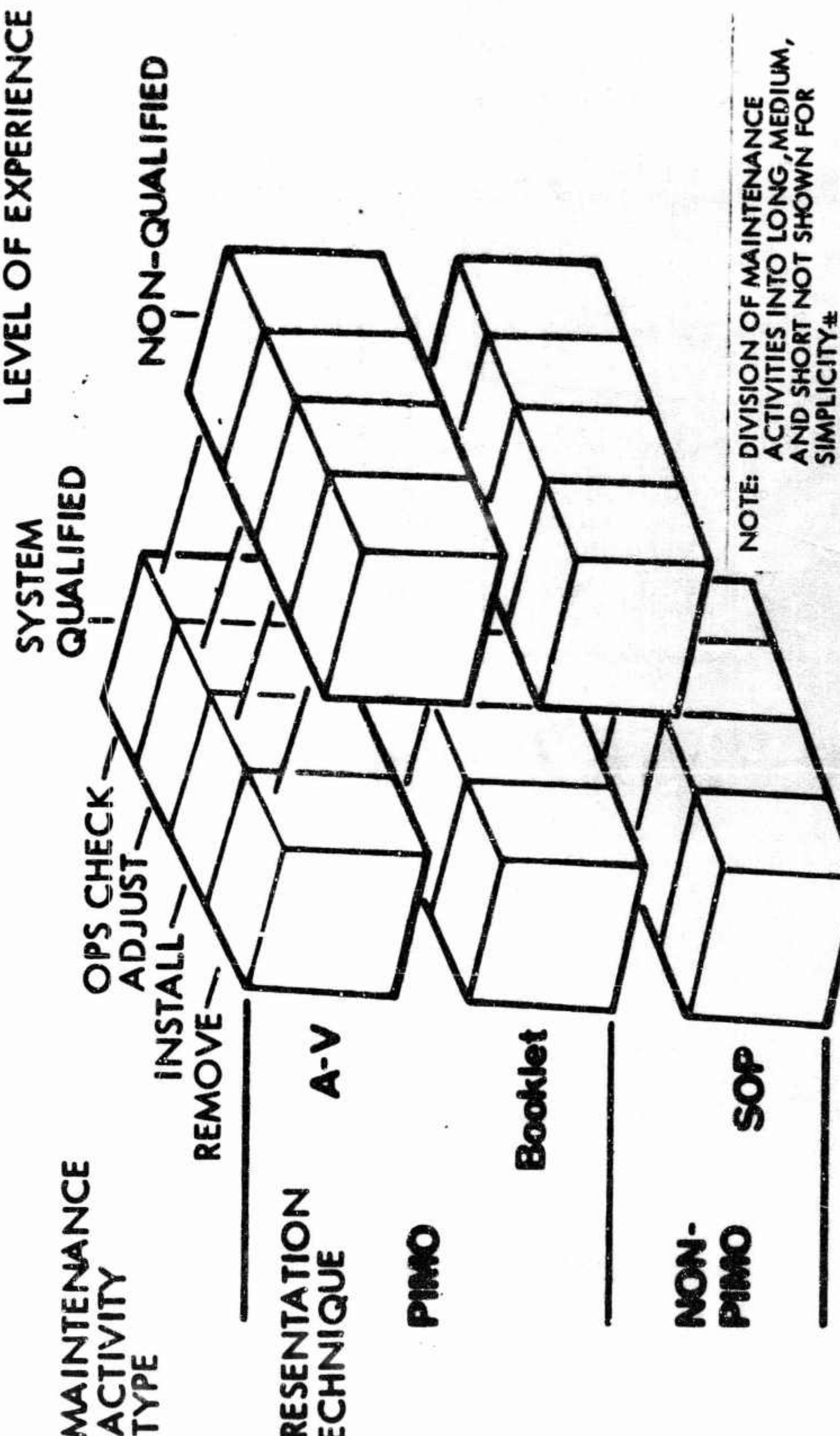

Figure 4-2. PIMO Field Test Experimental Design

a) Remove - removal of a bad component from the system.

b) Install - installation of a good component into a system.

c) Adjust - adjusting of a component in a system that is out of tolerance.

d) Operational Checkout - testing of a system to verify that it is within tolerance.

Since for each of those maintenance functions there existed separate activities which varied widely with time, a decision was made arbitrarily to divide the activities associated under each function into three major groupings-- long, medium and short -- based on the number of steps involved to complete any given activity.

For the concurrent study to determine the effectiveness of the Troubleshooting Aids, the independent variable was the use of the TSA manuals balanced against troubleshooting activities performed under the on-going practices found at the base.

2) Dependent Variables -- The first dependent variable was the total time taken to complete a maintenance action. This was labeled Time-in-Function and abbreviated TIF. This time was recorded using minutes as the unit of measure. Performance error rate was the second dependent variable taken, with the ground rule that an error was committed when a subject omitted a task, performed the wrong task, or had to repeat the task or procedure.

3) Subjects -- Two groups of subjects were required. The first group was drawn somewhat at random from the population of experienced skilled technicians qualified to perform maintenance. The second group was selected

from the lower skill-level technicians and members of the Operational Maintenance Squadron who were not qualified to perform maintenance on the C-141A's (see Figure 4-3). Each member of the test group served as his own control, in that all subjects employed both techniques of data presentation. A split-half technique was used, whereby half of the members of each group were exposed to one mode of data presentation (e.g., booklets), while the other half of each group was exposed to the alternate mode of data presentation(e.g., audio-visual). Midway through the test, the data presentation modes were reversed. In this way, any effects due to the order of presentation mode were counteracted. Each group of subjects -- experienced and inexperienced -- was composed of 18 men of approximately similar background, time in service, age, and level of experience. It was not expected that an exact match could be made, since the selection of each individual rested in the hands of the Air Force, and that selection was predicated in part on the individual's availability. Nonetheless, demographic data on each group indicated that there was a high degree of within-group homogeneity. Another requirement established was that all subject participants could be made available throughout the field tests. That is, no losses in subjects would be encountered due to previously planned leaves or discharge from the service. This requirement placed further limitations on acquiring a precisely matched group.

While a control group was used, no personnel selection was necessary due to the nature of taking control group data. It was decided that the control data would be derived from maintenance times -- for the tasks under investigation with PIMO formats -- by specialists using

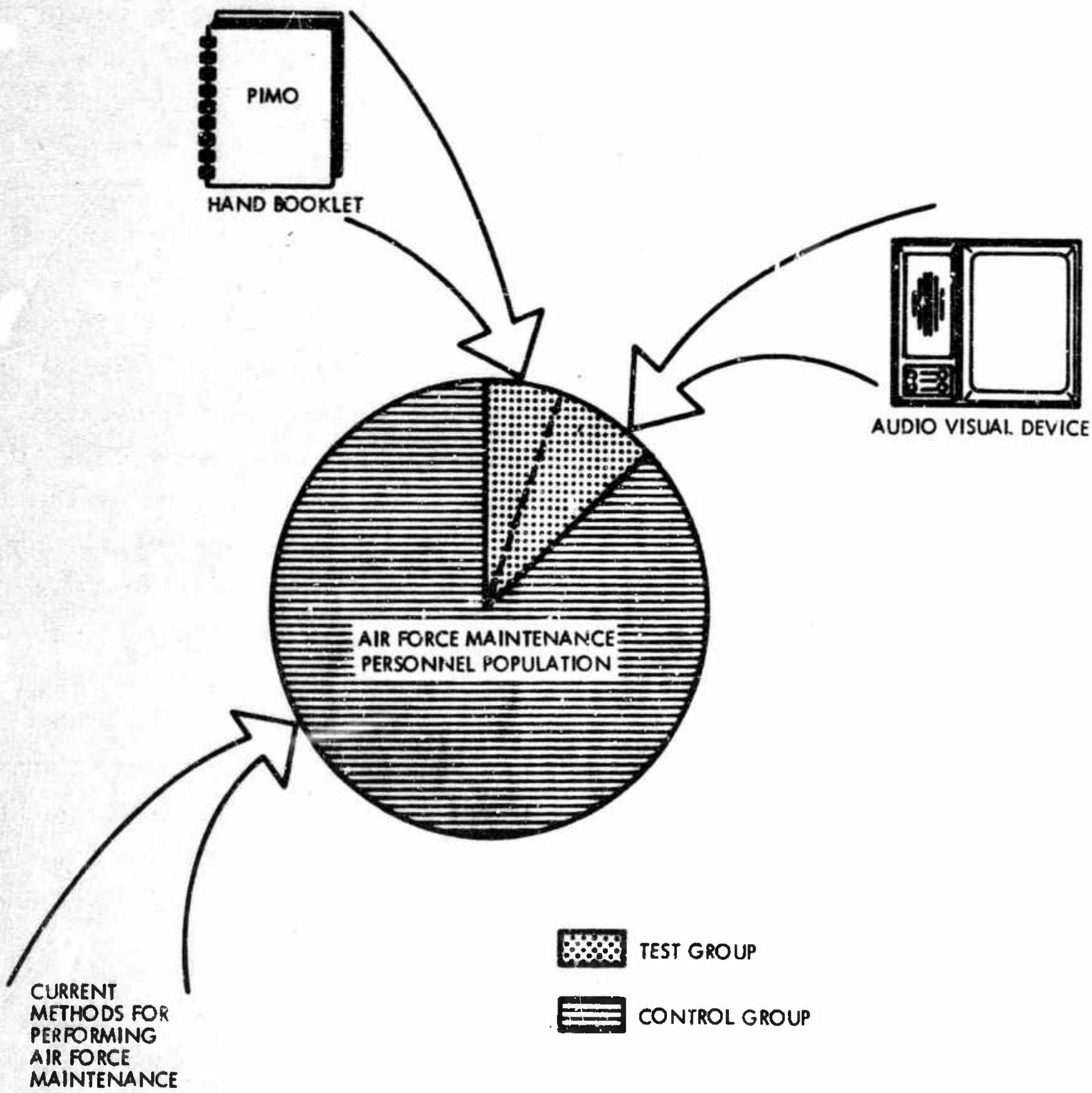

Figure 4-3. PIMO Field Test Subjects

standard on-going procedures in effect at the base. In this way, it was felt that a realistic comparison could be made later of the effects of the PIMO format. Control data were taken by trained PIMO team observers accompanying a regular base maintenance specialist during the course of his maintenance activities.

4) Observers -- Data collectors (observers) were selected jointly by the Air Force and Serendipity from the experienced maintenance specialist population at Charleston Air Force Base. It was necessary that our observers: 1) be knowledgeable in standard Air Force maintenance operations, 2) be specialists in at least one skill, and 3) hold a rank no less than sergeant. The need for these observers to be rated specialists was so that an inexperienced subject performing on-aircraft maintenance would be restrained from committing errors that would lead to immediate danger to himself, or subsequent catastrophic failure of the aircraft. In addition, Air Force policy requires that all on-aircraft maintenance be accomplished, or approved by, a rated specialist. Thus, maintenance actions performed by the inexperienced technician could be subsequently "signed-off", since it had been performed under the observation of the skilled technician/observer.

The observers were given a 5-day training class by a senior Serendipity staff. This course warned against the more obvious pitfalls of experimental data taking which must be avoided; and it reinforced the position that the observers were never to make a contribution to a maintenance action except in those cases where, in their judgment, the observed subject was about to commit an error which would place himself or the aircraft in danger.

5) <u>Equipment</u> -- The original test plan was to present the maintenance data in the audio-visual mode with an automated suite of equipment. This equipment suite was to consist of two major classes. One class was to be that of a local visual display device and handset for addressing the required information frame. The second class -- to be contained in a trailer located near the flight line -- was to be comprised of audio equipment driven by a PDP-8 computer.

This automated audio-visual presentation equipment was designed to operate in the following way. First, the subject maintenance technician would call up an index of addresses to locate the desired maintenance information. Next, this address would be inserted into the automated system via the handset. The trailer audio equipment computer would begin search of a master audio track to locate the activity called for. Once located, the audio information would transfer to one of ten satellite recorders, where it was made available to the maintenance technician. At the same time, the visual information data base would be searched for the addressed frame locally, at the visual device. It became obvious when the visual information was ready, since that frame would be projected to, or identified by, the technician. A ready light on the handset indicated that the audio information was also ready to begin. This system was so designed that once it was accessed, the audio and visual information were locked in synchrony. This system would give the technician the potential capability of complete random access to any information frame, together with an unlimited number of repeat audio bursts, as desired -- again on a random basis.

A requirement analysis study was conducted first in order to determine the operational characteristics necessary for the audio-visual system. These requirements were translated into engineering design specifications, and subcontracts were let for procurement of the actual equipment. The basic audio equipment was manufactured and assembled by Babcock Electronics Corporation of Costa Mesa, California. The tape drives for the audio equipment were manufactured by Telectro Corporation of New York. The visual device selected was the Republic Aviation Corporation - Fairchild-Hiller Division's Micro-Vue, Mark IIb. The Micro-Vue unit could store a maximum of ten microfische; each fische was capable of reproducing a page matrix 69 x 69 frames. These fische measured approximately 4 x 5 inches.

The audio equipment was to be controlled exclusively by the PDP-8 computer. That computer was to be augmented by a buffer unit, comprised of Digital Electronic Corporation modules, but designed by Serendipity staff and assembled on subcontract. A master audio recording console was designed by Serendipity, fabricated by Babcock Electronics, and installed at Serendipity's Western Division offices at Chatsworth, California. This recording console automatically recorded the necessary tone codes for proper stop-start, address identification. Miscellaneous units of GFE electronics completed the equipment suite, e.g., power supplies and intercoms. A professional announcer was employed by Serendipity to record the entire audio narration. It was found that approximately 80 hours were necessary to contain the entire maintenance data base.

According to the requirements established by Serendipity's

engineers, Charleston Air Force Base civil engineers designed and constructed cable-runs from the audio equipment trailer to six maintenance locations on the base. This provided a hard-wire link between the Micro-Vue used locally at the aircraft, and the trailer which then supplied both power and a signal path for address codes and subsequent narration.

Five weeks before the data taking phase of the field test was to begin, all patents, plans, spares and technical personnel associated with the Micro-Vue were acquired from Fairchild-Hiller by Microform Data Corporation of Palo Alto, California. Conditions associated with that transfer obviated production of updated microfische necessary for the accomplishment of the field test at Charleston. Therefore, it became necessary to substitute other audio-visual equipment for that which was originally intended to be used.[1]

A search of the available audio-visual devices disclosed a unit which represented the least compromise from the original concept. This unit was manufactured by Audiscan Incorporated of Bellevue, Washington (see Figure 4-4). While the Audiscan had neither complete random access nor audio repeatability, it was felt that through the judicious organization of the data and through the use of some manual narration techniques, the disadvantages, if any, would be greatly lessened. The Audiscan device weighed 12-1/2 lbs., was slightly more than 3 cu. ft. and used a standard 110 volt power source. Information for display was stored in 2-sided cartridges; one side contained the visual information on single-frame 16 mm. motion picture film, and

1 Concurrently, we encountered considerable difficulties in getting the audio equipment operational. Although these difficulties were being overcome, it was at the expense of manhours which would be wasted if the Micro-Vue could not be used.

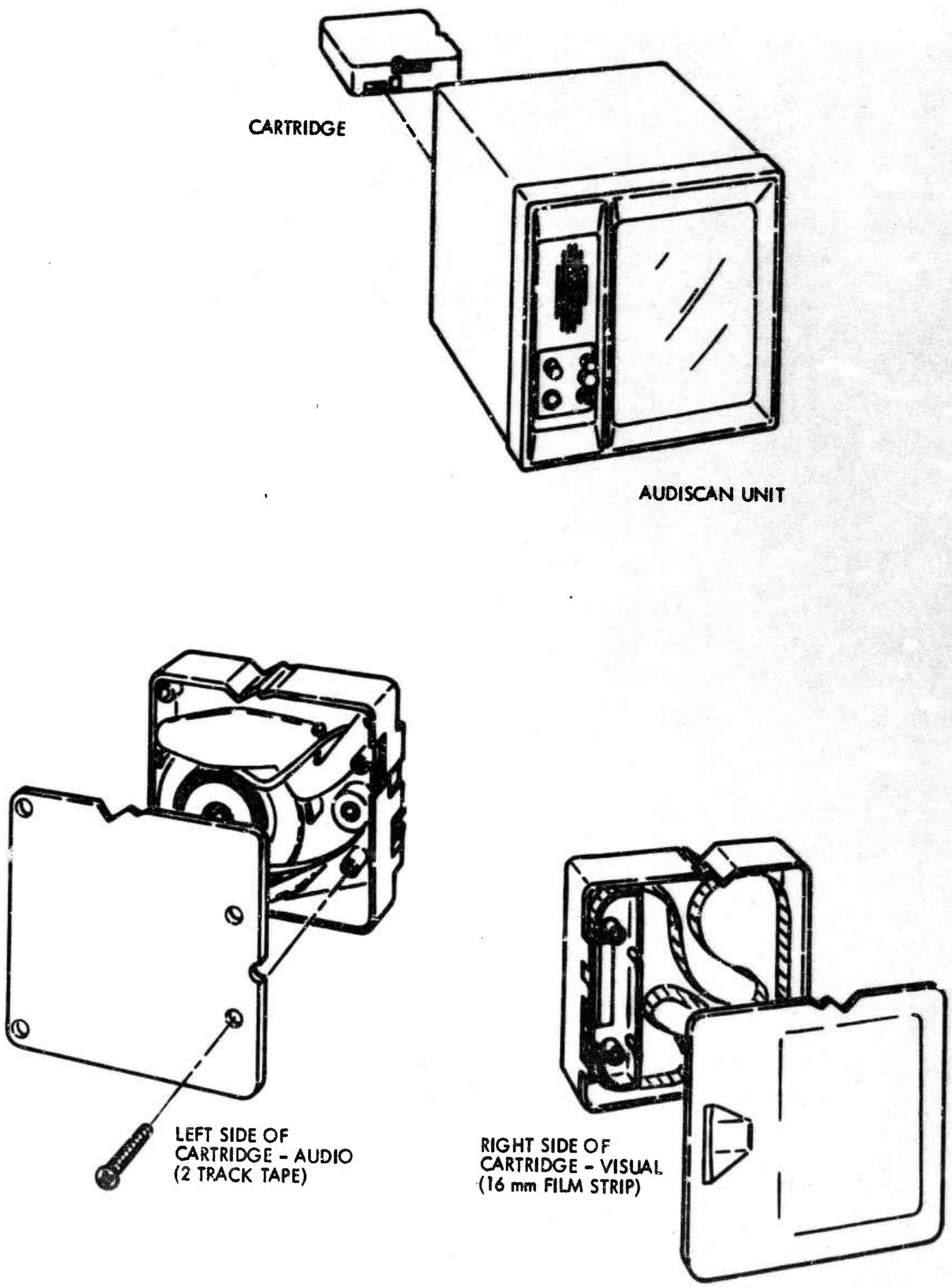

Figure 4-4. Audiscan Audio-Visual Device

the other side contained the audio information on standard 1/4 inch recording tape. The capacity of each cartridge was limited to 225 frames of visual, and 30 minutes of continuous audio.

The Audiscan electronic logic circuits were so designed that the information for display was programmed to sequence upon the request of the operator. Inasmuch as there was no capability to skip-step forward (other than in real time), it was necessary to place no more than one maintenance activity in a cartridge. While this provided a semi-random access -- the first frame for each activity was randomly accessible -- it meant that the maximum capability for each cartridge would rarely be realized. As a consequence, 146 cartridges were necessary to contain the data base. And, since two complete sets of data were thought to be necessary, a total of 292 cartridges were used. Because the Audiscan system was completely self-contained, requirement for the trailer audio no longer existed; therefore, a decision was made to close down the trailer. The narration heretofore recorded for the trailer system, was then transferred to the appropriate Audiscan cartridges. The visual material (pictorial) was photographed and reproduced on 16 mm. motion picture film as necessary for inclusion in the Audiscan cartridges. Each cartridge was separately and exhaustively inspected to ensure that the corresponding visual and audio material were loaded in the same cartridge and in synchrony. Arrangements were made through the base to provide a source of 110 volt, 60 cycle, a.c. power at each aircraft while maintenance was being performed by a PIMO subject using the Audiscan.

The visual-only material (booklets) (see Figure 4-5) required just that they be updated to include the latest

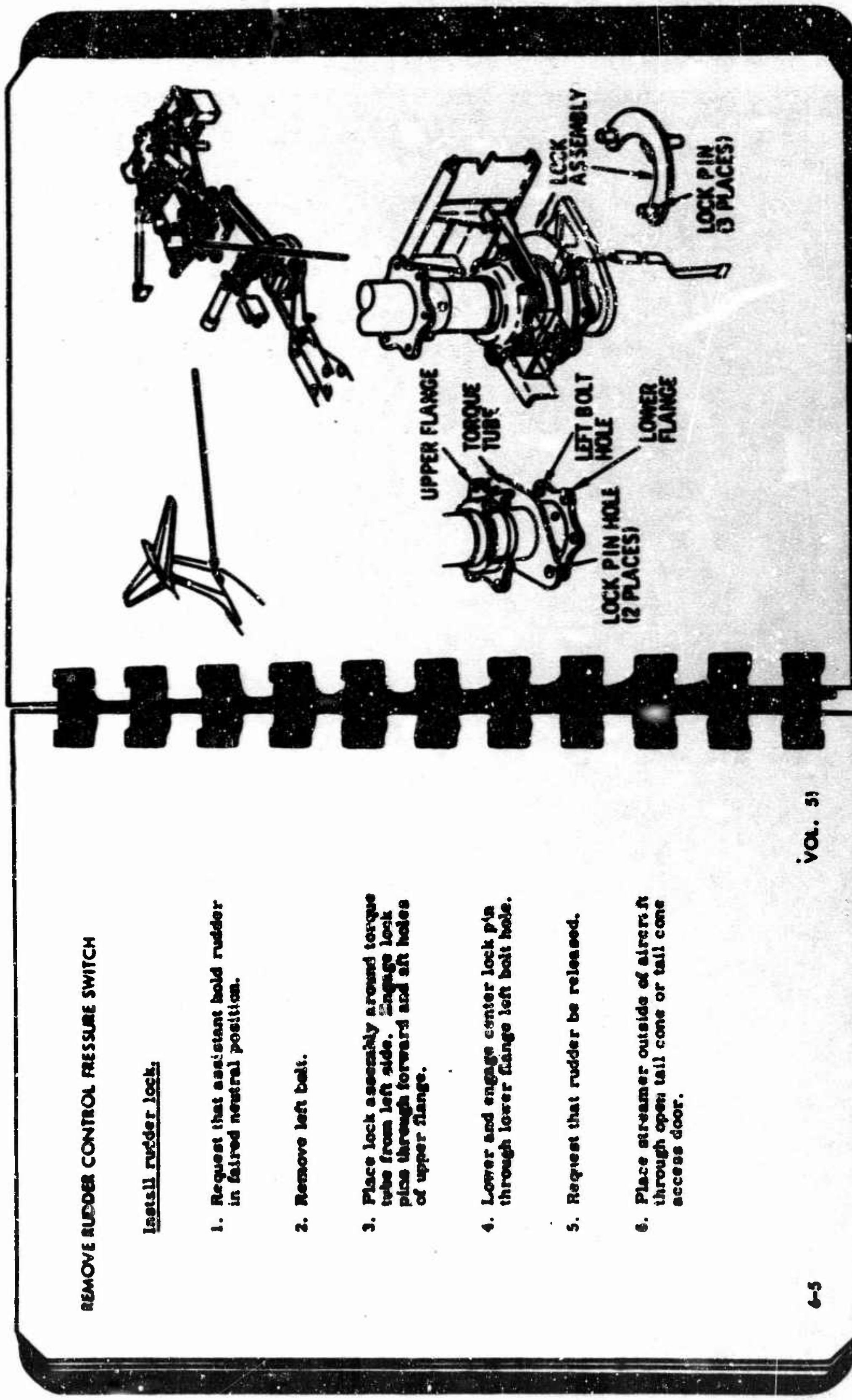

Figure 4-5. Visual Only (Booklet) Mode

equipment modifications. The necessary change pages were then inserted into the series of volumes.

Each observer was supplied with a watch suitable for timing the maintenance activities under observation, and a clipboard with data collection sheets. Miscellaneous equipment such as pencils, erasers, etc. was also provided. Electronic test equipment, tools and other maintenance hardware were obtained from the particular maintenance shops as needed.

A ready room was provided in a maintenance dock for the subjects, observers and dispatcher. Telephone service was also provided for the ready room, so that contact could be made with the maintenance shops and the base maintenance dispatch office.

6) Procedure - General -- Subsequent to the selection of both observer and subject personnel, and prior to the onset of data collection, a training course was given in order to: 1) orient the team to the methods and goals of the study, 2) caution them against violating certain primary and basic principles of experimentation, and 3) create a rapport between Air Force and Serendipity personnel. At that time, instruction was given in the use of the Audiscan, PIMO booklets and the Troubleshooting Aids.

As noted earlier, there were two subject groups. The first group, called Group A, included experienced, qualified maintenance specialists. The second group, called Group B, contained apprentice or inexperienced technicians. Half of the members from each group began the study using the audio-visual mode, and the other half of the group began the study using the print mode. Halfway through the test, these groups were inverted so that

each group would experience both presentation modes, and ordering effects would be somewhat controlled.

When an assignment for aircraft maintenance came in, the subject and his observer, together with the necessary data and tools, went to the aircraft. (See Figure 4-6). Once there, with all tools and maintenance data made ready, the activity was begun. The observer, a qualified specialist, recorded the elapsed time. Upon completion of the maintenance activity, the elapsed time was noted and the proper aircraft maintenance documentation was completed. In those cases where the subject was inexperienced, the observer certified the maintenance activity as to its completeness and accuracy. The subject and observer then redurned to the ready room, where the observer reported the Time-in-Function (TIF) and errors to the watch supervisor. At this point, both subject and observer were considered to be available for any subsequent, appropriate maintenance assignments.

7) <u>Procedure - Specific</u> -- Upon notification that an aircraft required maintenance, Serendipity personnel decided which data presentation mode would be used and which test group, A or B, would perform the maintenance. This decision was based upon a prearranged schedule that was intended to guarantee that the correct number of data points would be taken for each cell. This schedule requirement matrix was updated on a periodic basis as the maintenance data were accumulated in order to ensure that no more sample points were taken for any given activity than was actually required.

Appropriate PIMO booklet or audio-visual device and necessary cartridge was taken from the library maintained in the PIMO work-center ready room. Once at the work site, the observer prepared the necessary equipment

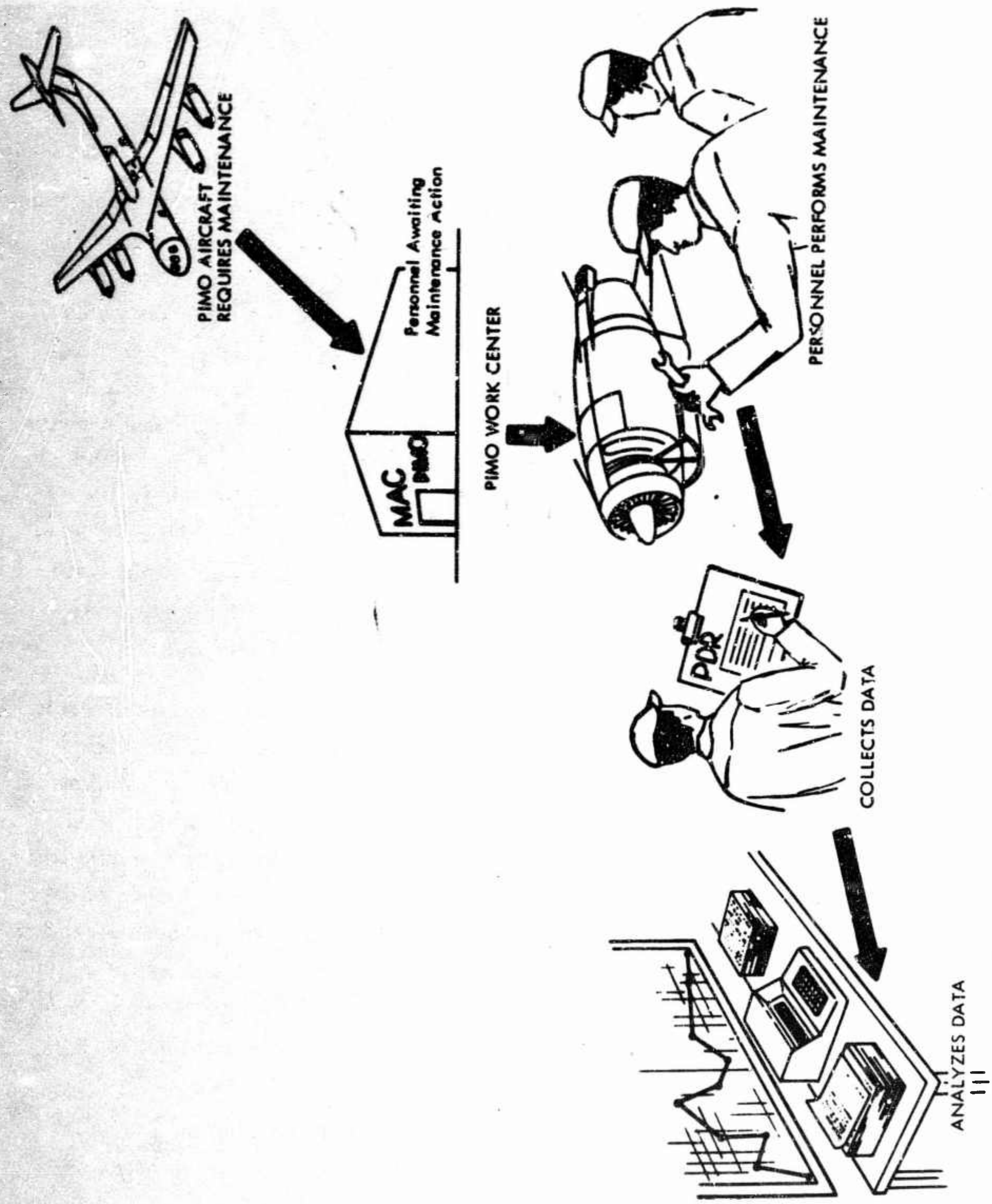

Figure 4-6. PIMO Field Test Procedure

if applicable, and prior to beginning maintenance, the observer noted all necessary data for identifying the maintenance action to be initiated, e.g., job control number, worker's name and number, aircraft serial number, flying hours, etc. Once these data were recorded, the observer noted the time maintenance actually began. If at any time the maintenance was stopped, either because of completion or delay, the observer again recorded the stop time. In these instances where a delay was experienced, a continuation of maintenance was recorded and a new start/stop time entered. The observer not only recorded the time data but also witnessed errors committed during the execution of maintenance. These errors were coded and recorded on an error sheet attached to a Serendipity designed PIMO Data Record (PDR). On this card, the following data were recorded: (See Figure 4-7).

a) Air Force job control number -- necessary for relating the maintenance action to Air Force records.

b) Aircraft serial number -- necessary for performing progressive on-going analyses of aircraft status.

c) Technician performing maintenance -- necessary for analyses at individual level.

d) Aircraft system work unit code and function -- all necessary for data organization.

It should be noted here that data collection entailed monitoring of two separate parameters, as implied above -- the elapsed time to perform the maintenance, called Time-in-Function, and error rate. The time data included only that time expended against actual maintenance. Travel time, set-up time, put-away time, wait-time for parts acquisition, etc., were excluded from the Time-in-

COMPANY
CONFIDENTIAL

PIMO Data Record

HENDERSON

JOB CONTROL NUMBER	AIRCRAFT SERIAL NUMBER	AIRCRAFT HOURS	MAN NO.	DATE
001-0001	6A4126	4503.7	H-5210	MO 01 DAY 01

EQUIPMENT NOMENCLATURE (AIRCRAFT SYSTEM): APN 59 B SEARCH RADAR SYSTEM E.T.

LOCATION ON A/C	LOCATION SHOP	WUC	ACTION TAKEN	HOW MAL	PART NAME (Include serial number for shop action)	START TIME	STOP TIME	[illegible]	PIMO USED YES	PIMO USED NO
X		72A00	H	242	SEARCH RADAR	0910	0942	E.T. .32	[illegible]	

- DO NOT USE R&S CODES--USE P&Q INSTEAD
- USE REVERSE SIDE OF CARD FOR ACTIONS TAKEN IF NECESSARY
- USE ADDITIONAL CARDS IF NECESSARY

- DETAIL EACH MAINTENANCE ACTION:
  1) RECORD EACH ACTION PERFORMED SEPARATELY
  2) INDICATE TROUBLESHOOTING TIME
  3) INDICATE OPERATIONAL CHECKOUT TIME
- SHOW START AND STOP TIMES FOR EACH ACTION TAKEN. SHOW ONLY ACTUAL MAINTENANCE TIMES OMITTING TRAVEL AND OTHER NECESSARY DELAYS.
- PLEASE BE SPECIFIC ON PART NAMES
- WHEN REPARABLE PARTS ARE REMOVED OR REPLACED, COMPLETE OTHER SIDE OF FORM

THIS INFORMATION WILL BE USED TO TEST THE EFFECTIVENESS OF THE PIMO PRESENTATION SYSTEM

Thanks for your cooperation

Figure 4-7. Example of PIMO Data Record (PDR) Card

Function data. Error data collection was somewhat more complex. In order for the data collector or observer to identify errors, he must first follow the instructions given by the job guide. In those instances where a member of the control group was performing maintenance -- that is, performing maintenance without the use of technical orders or job guides -- the observer had to be particularly attentive in order to identify procedural errors. In those cases where the subject was a member of Group B -- the unskilled group -- the observer assigned was a skilled technician who normally would work on the affected system. At no time was this observer to aid the unskilled technician on maintenance performance except, as noted above, when an act would lead to immediate harm to either the subject or the aircraft.

Under normal conditions, observers, Serendipity personnel, and the unskilled group of technicians would reside in the work-center ready room. The skilled group subject personnel normally remained active in their respective shops until called upon by the PIMO work center.

8) Data Requirements -- The reader's attention is directed back to Figure 4-2 which graphically illustrates the test design model. Note that this test design model has a total of 60 cells. Experimental design led to the need for 20 sample points per cell -- for a total of 1,200 sample points in all. In addition, 20 sample points per cell were required for the TSA effectiveness study.

Upon examination of the historical maintenance actions data associated with C-141A aircraft assigned to Charleston Air Force Base, it was predicted that a maximum of 4-1/2 months would be required to obtain

these sample points. This was based on separating the experimental subject teams in two shifts, 5 days a week. Since the schedule would extend through the Thanksgiving, Christmas and New Year holidays, an allowance was made for possible reduction in the data taking rate during that time. A master data-taking/personnel-assignment matrix was generated as a management tool in order that data would be taken for all cells without the expenditure of unnecessary resources.

Although the field test data-taking phase schedule had been predicated on historical data as mentioned above, experience in the field quickly demonstrated that a significantly lesser failure rate was in effect. There were no obvious clues as to why this was so.[1] Nonetheless, it became obvious very early that if the lesser failure rate were to continue, it would be necessary to extend the data collecting activities for an additional 12 or 14 months. Since almost all C-141's were candidate aircraft for this study, instead of the few originally assigned, the problem seemed severe indeed. The solution was suggested by Lt. Col. Henzi, Deputy Chief of Maintenance. He suggested that we perform the special maintenance activities on NORS and IRAN aircraft. This allowed us to accelerate our data taking rate to the point where as it later developed, we were able to find time to perform a heretofore unanticipated special test at the end of the main study.

It should be made clear, that the use of the term, "special" does not mean that faulted components or systems were inserted into the aircraft for subsequent maintenance, to be accomplished by PIMO subjects. In fact, this was not required, because the maintenance specialists acting as subjects in the main study were not required to trouble-

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[1] In fact, no attempt will be made here to explain this phenomena.

shoot. Consequently, the condition of the maintained item was, in a sense, irrelevant.

Of course, this procedure was not possible for the TSA effectiveness study; thus, all troubleshooting data were collected on actual malfunctions. The experimental team felt that the use of the IRAN and NORS aircraft in no way compromised the integrity of the field study. Indeed, since a significant increase was possible in the control which one could exercise over the experimental situation, it was felt that the derived data had greater reliability and validity.

It had been anticipated originally that for each subject to act as his own control, he would be assigned the identical maintenance activity under all modes of information presentation. In a fair number of cases, it was possible to accomplish this, but because of the exigencies which prevailed at Charleston -- indeed, not an altogether surprising situation -- it was impossible to maintain such strict control for all cases. Later, during the data analysis (described in Section V), a Mann-Whitney U test was applied to data from the more controlled cases as a check against the analysis performed with the analysis of variance model.

3. Special Test

Since the actual data collection rate exceeded that which was originally anticipated (see Figure 4-8), it was possible to conduct a special test at the end of the basic study. It was the purpose of this study to contrast the performance of unskilled technicians using standard Air Force T.O.'s, against experienced technicians also using those T.O.'s. Half of the inexperienced subjects had had recent experience with similar maintenance actions using PIMO instructions, while the remain-

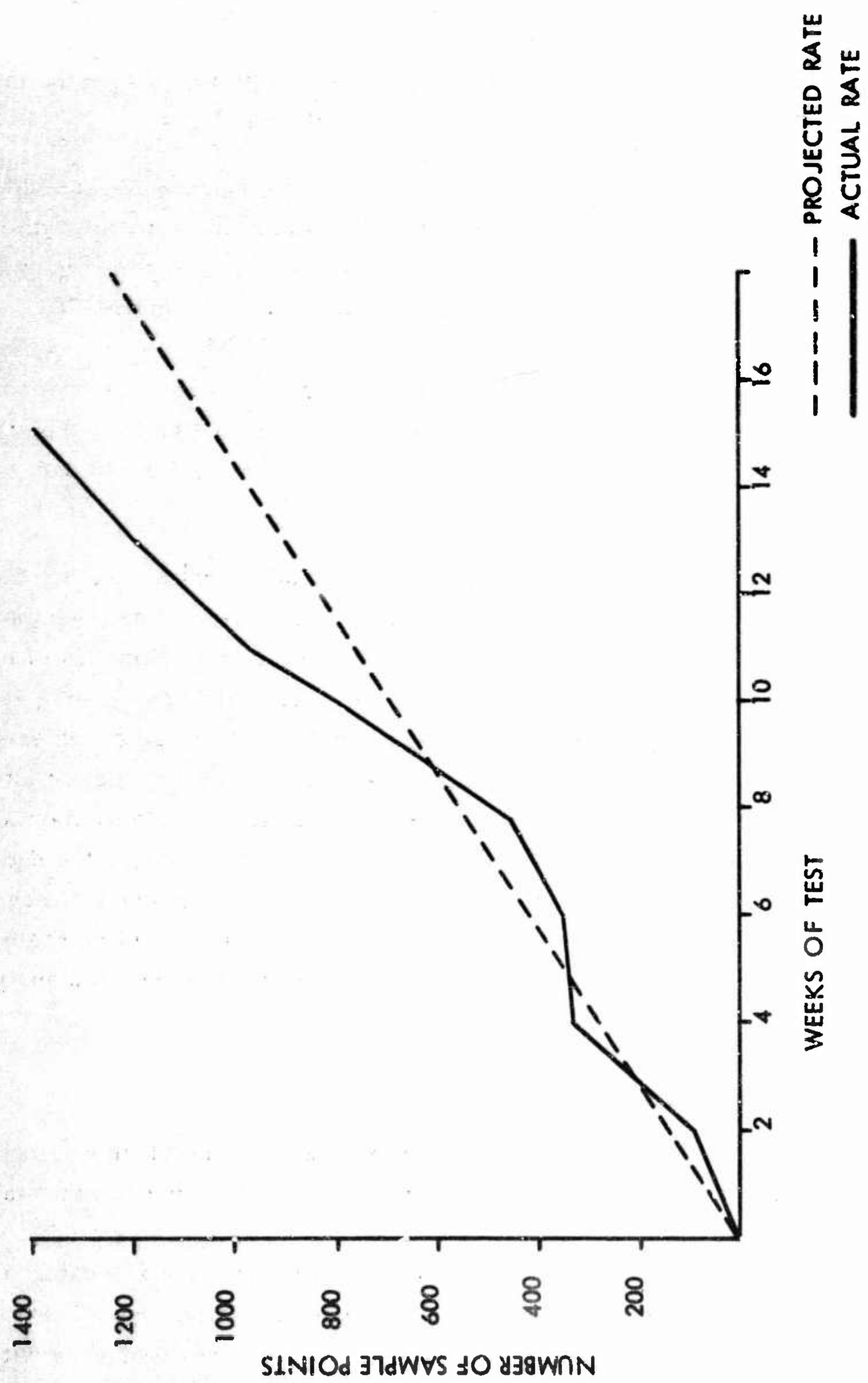

Figure 4-8. Projected vs. Actual Data Collection Rates

der had no prior experience in the maintenance activity assigned. Here again, the dependent variables were Time-in-Function (TIF) and errors. Time data was collected in the same manner as for the basic study described above.

Four types of procedural errors were defined during the test. These were:

a. Type A -- maintenance step was performed either out of sequence or omitted.

b. Type B -- maintenance step was performed incorrectly.

c. Type C -- indication called for was erroneously interpreted and was not correctly obtained.

d. Type Ω -- maintenance action was terminated due to lack of experience or lack of information.

This study was accomplished during the last two weeks of activities at Charleston Air Force Base, and only a sub-set of the PIMO subjects were employed.

SECTION V

DATA ANALYSIS

A. ANALYTICAL MODELS

The statistical techniques for analysis of the PIMO field test data were selected to provide precision and power to the conclusions and inferences drawn from those results. For the main study -- comparing the main effects of the PIMO formatting technique -- the analysis-of-variance model was used. It is generally accepted that the factorial analysis-of-variance is the most appropriate method for determining both the independent and interactive effects of two or more independent variables on a dependent variable. In the past, most research effort was designed to study one independent variable and its contribution on the effect of the relevant dependent variable. More recent research strategy,however, calls for multi-variate research designs. Some authorities on research techniques now believe that multi-variate experimental designs are more valid than the single variate type, because it more closely resembles the complex interactions that one finds in a real world situation (Kerlinger, 1966).

The purpose of any statistical test is to determine whether or not the null hypothesis should be rejected on the basis of the obtained sample. The risk associated with the decision to reject the null hypothesis -- or failure to reject the hypothesis -- is related primarily to the level of significance selected as the criteria for rejection. As the level is increased (e.g., from 1% to 5% to 10%, etc.), one increases the risk of rejecting the null hypothesis when in fact there is no difference in the real situation. Researchers generally use the 1% or 5% level of significance in order to reduce this risk.[1] In a practical situation, one is generally justified in using even a higher level (e.g., 8%-15%) depending on the consequences of the risk. A conservative 5% level is

[1] An associated risk is one of failing to reject the null hypothesis when there is a t e difference in the real situation.

used for the PIMO test since: 1) any result must be examined in terms of practical differences, 2) no difference has as great a meaning as differences -- especially for presentation modes and skill levels, 3) the impact of the test results are sufficiently large that the test must withstand both academic and practical scrutiny, and 4) we have no basis for selecting any higher level except our own judgment.

B. ANALYTICAL PROCEDURES

During the first weeks of testing, primary analysis began as soon as initial data became available. Thereafter, observed maintenance times (TIF) were accumulated according to their appropriate cell in the experimental design; and, on a weekly basis, mean times were computed for each cell.' From this, a weekly report was compiled and distributed. (See Figure 5-1). This report consisted of a table showing mean times and sample size for each cell, and contained graphs which contrasted the rate of actual data collection against the expected rate derived under the original projections. This technique provided a useful management tool to assess progress and to aid the field personnel.

At the conclusion of the field test, all data were transferred from PDR cards onto IBM keypunched cards. This allowed the analysts to sort the data along different dimensions, leading to computer printouts which presented the data under various aspects of consideration, e.g., ordered by cells according to original matrix, technicians, or maintenance activities.

The products of the analytical procedures discussed below are presented in the remaining sections of this report.

1. Basic Study

The dependent variables taken for this design were Time-in-Function (elapsed time to complete the maintenance activity), and errors. Since no errors were observed for any maintenance activity accomplished through the use of the PIMO Job Guides, no statistical analysis was performed.

		A-V						BOOKLET						SOP					
		LONG		MED.		SHORT		LONG		MED.		SHORT		LONG		MED.		SHORT	
		N	M	N	M	N	M	N	M	N	M	N	M	N	M	N	M	N	M
OP.CH.	A	0		9	18.9	14	8.8	3	67.7	16	17.9	6	8.5	9	8.9	3	7.3	7	14.7
	B	0		2	57.5	19	13.3	8	80.5	11	20.5	11	10.2						
REM.	A	17	17.9	13	9.2	4	3.8	10	11.7	16	4.4	24	3.0	11	4.9	13	3.4	14	1.1
	B	10	23.9	12	12.0	12	5.5	12	29.2	10	7.5	15	4.7						
INST.	A	17	4.8	13	5.4	4	4.0	10	4.0	12	5.4	23	2.5	11	4.7	13	2.4	14	2.2
	B	10	9.9	12	7.9	12	4.3	10	7.8	10	4.0	15	3.7						
ADJ.	A			0						12	108.4					7	90.1		
	B			4	134.3					10	119.8								

	TSA		SOP	
	N	M	N	M
TROUBLESHOOT SYSTEM	9	18.3	1	25.0

Figure 5-1. Example of Weekly Compilations

Inspection of the TIF data indicated a log normal distribution. Since this is generally the distribution observed and accepted for maintenance performance times, all scores were transformed into their log equivalents.

In order to increase the precision of the test, it was decided to separate the analysis for each function. This was reasonable, since large differences between the various functions are expected simply due to the differences in the work involved.

An assumption was made, supported by preliminary calculations, that the observed TIF differences between maintenance activities were not a function of the treatment effects. With that in mind, and in order to exclude possible obscuring effects due to the variance contributed by those different activities, the factorial design was partitioned at the function level. As discussed earlier, this led to two types of analysis models for each of the four types of maintenance activities (i.e., Operational Checkout, Remove, Install and Adjust). These were: a) 2 x 2 x 3 models in which PIMO audio-visual and booklet modes were tested with respect to the two skill levels and the three function lengths; and b) three 3 x 3 models where the two PIMO modes were contrasted with Standard Operating Procedures. (See Figure 5-2).

The method of calculation for the analysis-of-variance is that described in Lindquist (1953).

Specific comparisons made were as follows:

1. PIMO audio-visual versus PIMO booklet presentation modes -- these presentation modes were contrasted using the performance times (TIF) of the experienced and apprentice technicians.

2. Experienced versus Apprentice Technicians -- TIF of the two groups of technicians were compared for both the audio-visual and booklet presentation modes.

2X2X3 FACTORIAL EXPERIMENT

AUDIO-VISUAL						BOOKLET					
EXPERIENCED			INEXPERIENCED			EXPERIENCED			INEXPERIENCED		
LONG	MED.	SHORT	LONG	MED.	SHORT	LONG	MED.	SHORT	LONG	MED.	SHORT

3X3 FACTORIAL EXPERIMENT

AUDIO-VISUAL			BOOKLET			SOP		
LONG	MED	SHORT	LONG	MED	SHORT	LONG	MED	SHORT

Figure 5-2. Analysis of Variance Computational Models

3. PIMO versus Standard Operating Procedures -- TIF of experienced technicians using PIMO were compared to the same technicians when they used standard procedures.

The model employed for the Adjust function was a 2 x 2 design -- A/V versus Booklets; Group A versus Group B; and Group A only contrasting A/V, booklet, and SOP. (Note: Only Group A -- (experienced) -- were permitted to use SOP). Rather than a factorial design, a simple randomized analysis-of-variance model was employed.

As mentioned in Section IV, the experimental controls which would have allowed each subject to perform maintenance on identical tasks under all modes of data presentation were not possible to enforce. Consequently, it was felt that some doubt might have been cast over the results gained from the analysis-of-variance. As a check on those results, it was decided to perform a Mann-Whitney U test. It is understood that the Mann-Whitney U, a non-parametric test and one which requires data only at the ordinal level of measurement, would not have the power of the analysis-of-variance. Nonetheless, it seemed both germane and important to test whether or not our two independent groups had been drawn from the same population. Siegel (1956) states that the Mann-Whitney U is one of the most powerful of the non-parametrics, "and it is a most useful alternative to the parametric $\underline{t}$ test when the researcher wishes to avoid the $\underline{t}$ test's assumptions, or when the measurement in the research is weaker than integral scaling". The method of calculation for this test was that described in Siegel.

2. TSA Effectiveness Study

For analysis of the data taken from the TSA Effectiveness Study, student's $\underline{t}$ was selected. It was used primarily because there was only one independent variable, and it is one of the most powerful parametric tests available. Calculations were performed according to the technique shown in Dixon and Massey (1957).

3. User Acceptance

The original plan was to use ^{2} and other applicable non-parametric models to test the significance of questionnaire responses. However, inspection of the data disclosed that exhaustive statistical analysis was unnecessary since the responses were overwhelmingly positive, e.g., 90%; 100%. Therefore, primarily descriptive statistics were used in this report, i.e., means, percents, etc. with some analysis using Fisher's Exact Probability Test.

4. Special Test (PIMO versus Technical Orders)

No inferential statistical tests were used, since so few sample points were collected. The data were accumulated and raw mean performance time was calculated. These means were displayed on bar-graphs, alongside corresponding mean times from the basic study.

Error rates observed during the special test were for a significance with χ^2 and Fisher's Exact Probability Test.

5. Learning Effects

Two analyses were performed to determine the learning effect present during the PIMO field test. Both of these are presented in a descriptive manner, with no statistical analysis supplied. For the learning curves, each series of four or more actions that involved the use of PIMO by an individual technician, on a specific maintenance activity, were identified and recorded. The ratio of the log-normal Standard Operating Procedure time, for subject activity by all experienced technicians, was computed and recorded according to its sequence in the performance series, i.e., first time performed, second time performed, and so forth. The ratios were averaged for experienced and inexperienced technicians by the repetitive action number and plots were drawn for each experience level respectively.

In addition to the learning curves taken from the performance times, a time change matrix was generated in the form of a three-by-three contingency table. Plotted in this matrix were the performance times by presentation mode for each occurrence of a particular maintenance activity as repeated by an individual technician. For each successive pair of actions, i.e., first and second, second and third, etc., the difference in the log performance times was recorded on the matrix. Following this, the average for each cell was calculated and the percentage of time change computed. It was felt that these time change matrices would offer supporting evidence for the occurrence of learning as demonstrated by the learning curves.

6. Systems Effectiveness/AMES Model

A determination of change in over-all systems effectiveness as a function of PIMO application was estimated through the use of the AMES Model. AMES, an acronym for Aircraft Maintenance Effectiveness Simulation, was developed early in the program by Serendipity, Inc. It is a digital simulation model programmed for the IBM 7094 and represents a technique of simulating a real system by means of a dynamic mathematical representation of that system. The AMES simulation model is discussed more fully in Section VII of this volume. In general, however, the AMES Model accepts data which represent the aircraft in terms of its major subsystems and their principal components. For example, failure rates, repair policy, spares level, and data reflecting scheduled and unscheduled maintenance for systems and sub systems are furnished to the simulation program. Furthermore, data are provided which specify the required types and numbers of personnel necessary to perform maintenance. Task performance times, and personnel reliability are also included in the data bank. The simulation model is driven by impressing mission demands. Results obtained from the various runs of this model are reported in Section VI of this volume.

SECTION VI

TEST RESULTS

A. INTRODUCTION

Stated broadly, the main purpose of the PIMO field test was to determine whether or not the newly formatted maintenance instructions could be instrumental in aircraft maintenance improvement. Since the major areas of consideration were: better utilization of resources (i.e., manpower), and reduction of costly and often dangerous maintenance performance errors, it is with emphasis on those points that the results of the data analysis will be presented.

B. PERFORMANCE DATA

Since no error was noted in over 1,000 observations of performance with PIMO, no comparison of error rate was made. Thus, the discussion of the results is limited to performance time. Previous analysis of maintenance records showed that the "normal" maintenance results in a fairly high error rate. Thus, it can be stated with a fairly high degree of confidence that PIMO resulted in a 100% reduction of error rate for the test. Any improvement in performance time discussed in this subsection should be viewed as an additional improvement beyond the 100% error reduction.

1. PIMO versus Standard Operating Procedures

The data for performance times were converted to log-normal equivalents, and the mean time for each condition was calculated. Those mean times are presented in bar graph form in Figure 6-1 and 6-2. It should be noted that only experienced technicians, i.e., 5-level, performed maintenance using Standard Operating Procedures. This was because it seemed to make no sense to allow an apprentice technician to perform maintenance using procedures for which he had no experience or training. Consequently, for comparison of Standard Operating Procedures only the 5-level, certified technicians were employed.

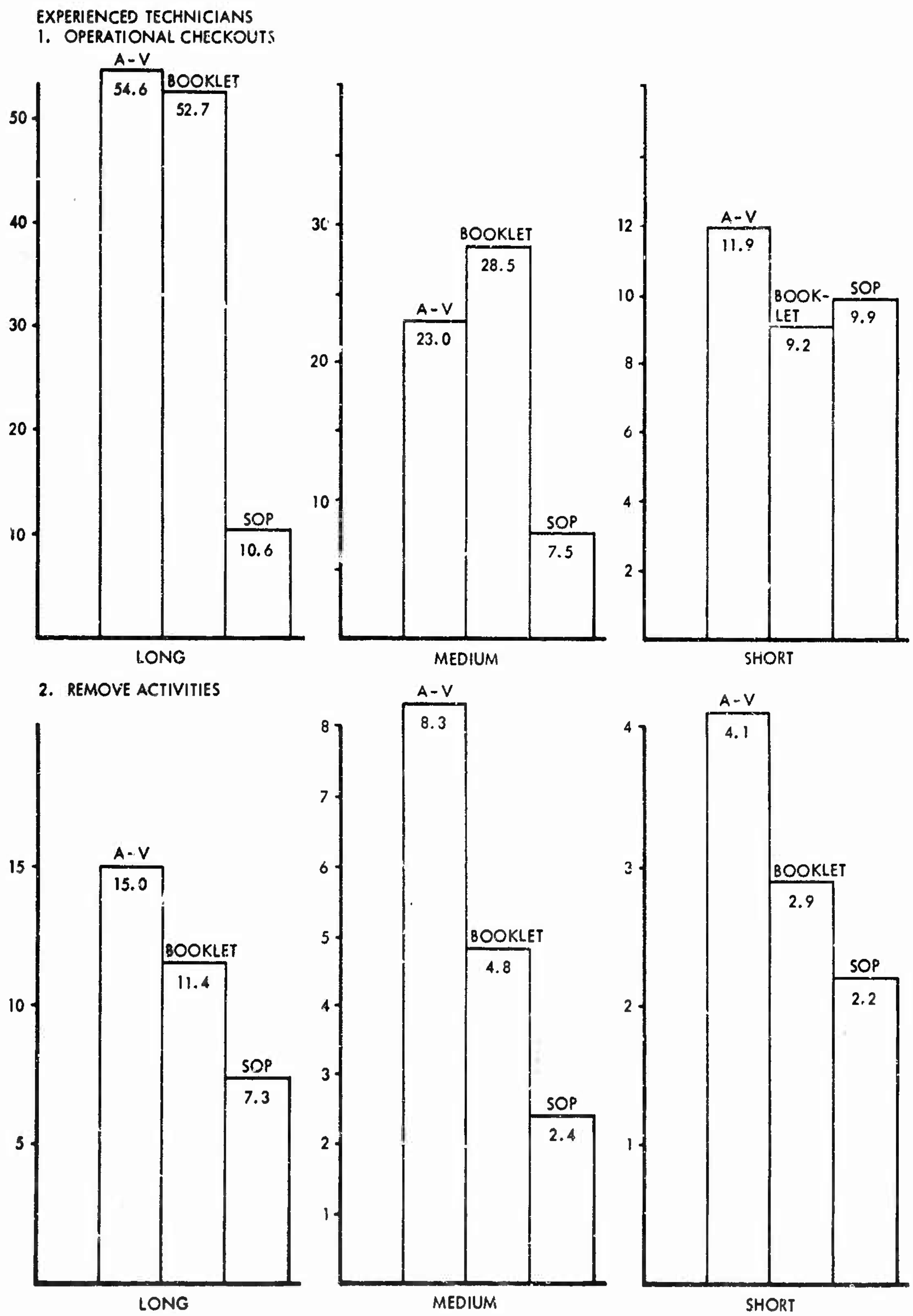

Figure 6-1 PIMO Audio-Visual vs. PIMO Booklet Presentation Modes vs. Standard Operating Procedure

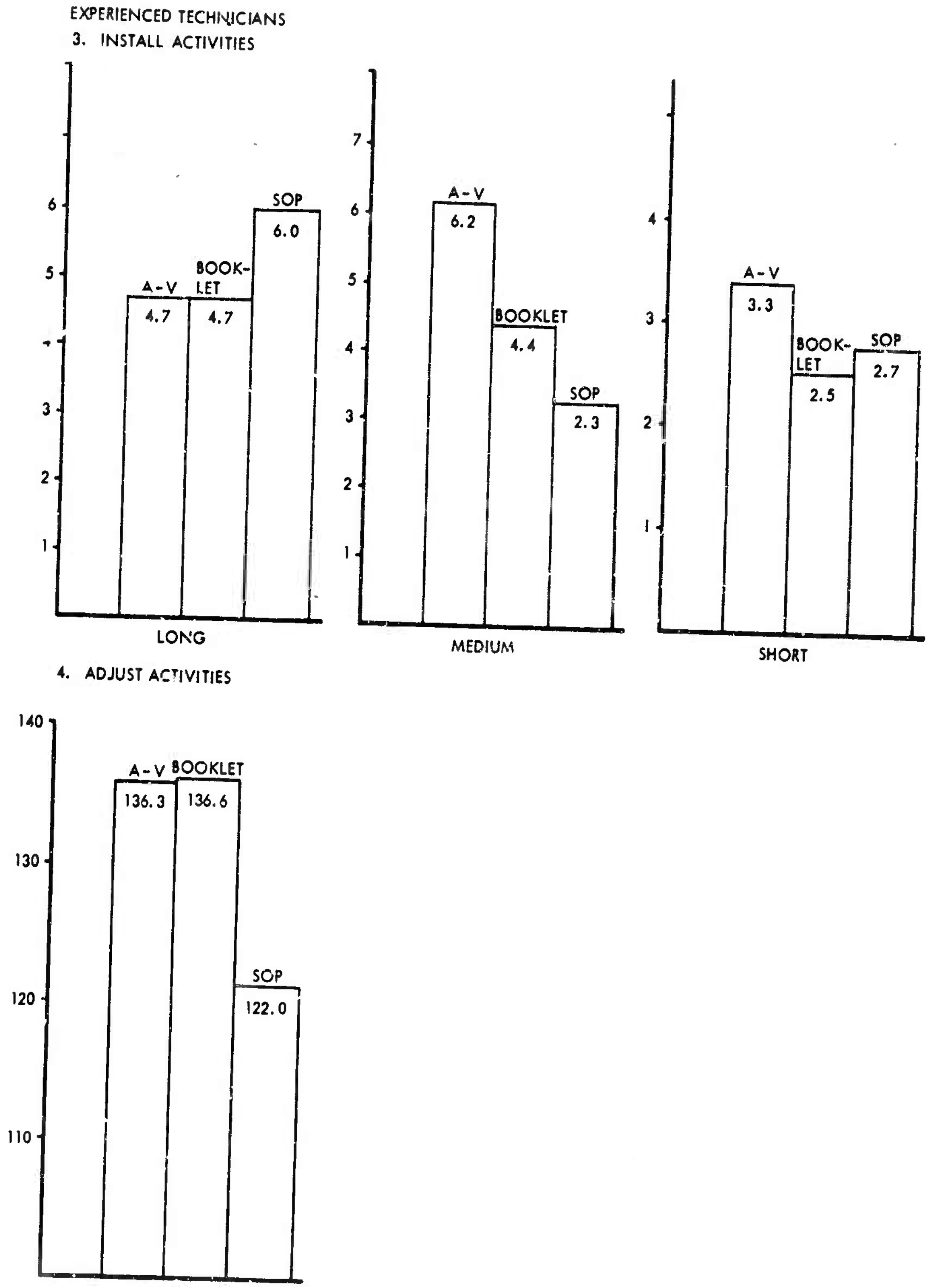

Figure 6-2 PIMO Audio-Visual vs. PIMO Booklet Presentation vs. Standard Operating Procedure

The data show, as illustrated in the figures, that the maintenance times were shorter for Standard Operating Procedures than for PIMO under either A-V or booklet presentation mode. This is not altogether unexpected, since the mean times do not reflect the level of performance eventually exhibited by the technicians subsequent to their learning. As will be seen later, it is possible for all technicians to approach the Standard Operating Procedure maintenance times as an asymptote. Thus, the average time with PIMO is a function of the number of samples obtained for a given activity. If we had conducted the test for a longer period of time and the learning curve observed held true, the PIMO time would probably be the same as the SOP time.

The mean times shown, do reflect that on the average, SOP require 35% less time than the PIMO audio-visual mode and 18% less time than the PIMO booklet mode of information presentation.

(The data collected for the effectiveness of the troubleshooting aids on the other hand, reflect that the use of these aids resulted in an 11% <u>decrease</u> in troubleshooting time (see Figure 6-3)).

There are some significant comparisons to which the reader's attention should be directed. Short Operational Checkouts, for example, indicate that there is a .7 minute real difference between booklets and the SOP, giving a difference of 7.6%; and a real difference of two minutes between A-V and SOP for a 16.8% difference. In a practical sense, this would indicate that the performance times with the PIMO presentation mode do indeed approximate those of the SOP. This is quite dramatic when one considers that the performance times described are mean times, as mentioned above, and do not reflect the steady reduction as the subjects learned. Other comparisons are equally dramatic. For example, medium Remove activities indicate real differences of approximately six minutes between audio-visual and SOP, and 2.4 minutes between booklet and SOP. For short Remove activities, the time differences are even less -- 1.9 for A-V versus SOP, and .7 minutes for booklet versus SOP. The other comparisons are also indicative of the close-

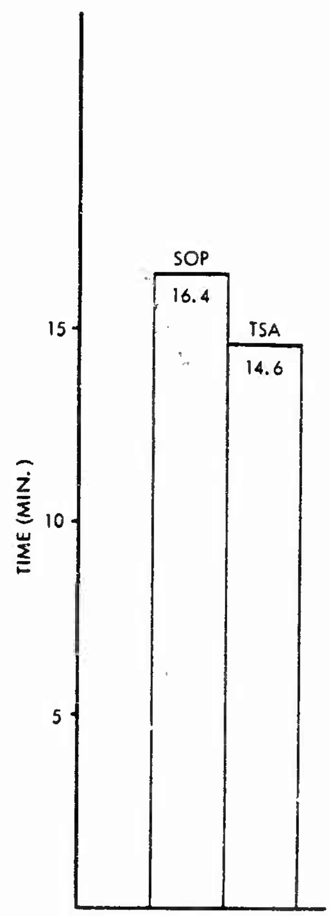

Figure 6-3 Comparison of TSA & SOP Mean Performance Time

ness of the performance times between presentation modes and the standard practices.

On the other hand, there are other instances reflected in Table 6-1 which indicate that for some activities there is divergence in performance times. A good example is that of long Operational Checkouts. Here, the time differences between A-V and SOP are 44 minutes, for an increase of 80.6%; and a time difference of 42.1 minutes for an increase of 79.9% for booklets versus SOP. There is reason to believe that this difference is due to shortcuts taken by the experienced technicians performing without data. These shortcuts may or may not provide an adequate check of the system of concern.

2. Comparison of Audio-Visual versus Booklet Presentation Mode

Figures 6-4 and 6-5 show the comparisons for audio-visual versus booklet presentation techniques, within the apprentice technician group. These bar charts were generated in much the same way as those described above. That is, log normal performance times in minutes were accumulated, their means calculated and the bar charts drawn. From observation, one can quickly see that in most cases there is relatively little real difference in the performance times for any activity, or activity duration, for audio-visual or booklet modes. In two instances, however, the times are, in terms of their percentages, somewhat large. Those two instances are for medium Install activities -- where the mean time for A-V was 6.6 minutes and the mean time for booklets was 4.4 minutes -- and medium Remove activities, where the mean time for A-V was 8.7 minutes and the mean time for booklets was 6.2 minutes.

Once again, one should be cautious in interpreting these data as representative of performance times which one might experience from the technicians in the field. Since they are means, they include the times during which learning occurred, and they are thus weighted in a direction which produces longer performance times.

OPERATIONAL CHECKOUT

	PRESENTATION MODE			COMPARISON			
	LOG NORMAL MEANS IN MINUTES			A-V VS. SOP		BOOKLET VS. SOP	
	A-V	BOOKLET	SOP	DIFFERENCE BETWEEN MEANS IN MINUTES	PERCENT DIFFER.	DIFFERENCE BETWEEN MEANS IN MINUTES	PERCENT DIFFER.
LONG	54.6	52.7	10.6	-44.0	-80.6	-42.1	-79.9
MEDIUM	23.0	28.5	7.5	-15.5	-67.3	-21.0	-73.7
SHORT	11.9	9.2	9.9	- 2.0	-16.8	+ .7	+ 7.6

REMOVE ACTIVITIES

	PRESENTATION MODE			COMPARISON			
	LOG NORMAL MEANS IN MINUTES			A-V VS. SOP		BOOKLET VS. SOP	
	A-V	BOOKLET	SOP	DIFFERENCE BETWEEN MEANS IN MINUTES	PERCENT DIFFER.	DIFFERENCE BETWEEN MEANS IN MINUTES	PERCENT DIFFER.
LONG	15.0	11.4	7.3	-7.7	-51.3	-4.1	-32.4
MEDIUM	8.3	4.2	2.4	-5.9	-71.0	-2.4	-50.0
SHORT	4.1	2.9	2.2	-1.9	-46.3	-0.7	-24.0

INSTALL ACTIVITIES

	PRESENTATION MODE			COMPARISON			
	LOG NORMAL MEANS IN MINUTES			A-V VS. SOP		BOOKLET VS. SOP	
	A-V	BOOKLET	SOP	DIFFERENCE BETWEEN MEANS IN MINUTES	PERCENT DIFFER.	DIFFERENCE BETWEEN MEANS IN MINUTES	PERCENT DIFFER.
LONG	4.7	4.7	6.0	+1.3	+27.6	+1.3	+27.6
MEDIUM	6.2	4.4	2.3	-3.9	-62.9	-2.1	-47.7
SHORT	3.3	2.5	2.7	-0.6	-18.2	+0.2	+8.0

ADJUST ACTIVITIES

	PRESENTATION MODE			COMPARISON			
	LOG NORMAL MEANS IN MINUTES			A-V VS. SOP		BOOKLET VS. SOP	
	A-V	BOOKLET	SOP	DIFFERENCE BETWEEN MEANS IN MINUTES	PERCENT DIFFER.	DIFFERENCE BETWEEN MEANS IN MINUTES	PERCENT DIFFER.
	136.3	136.6	122.0	-14.3	-10.5	-14.6	-10.7

Table 6-1 Within Group Comparisons, Group A (Experienced Technicians)

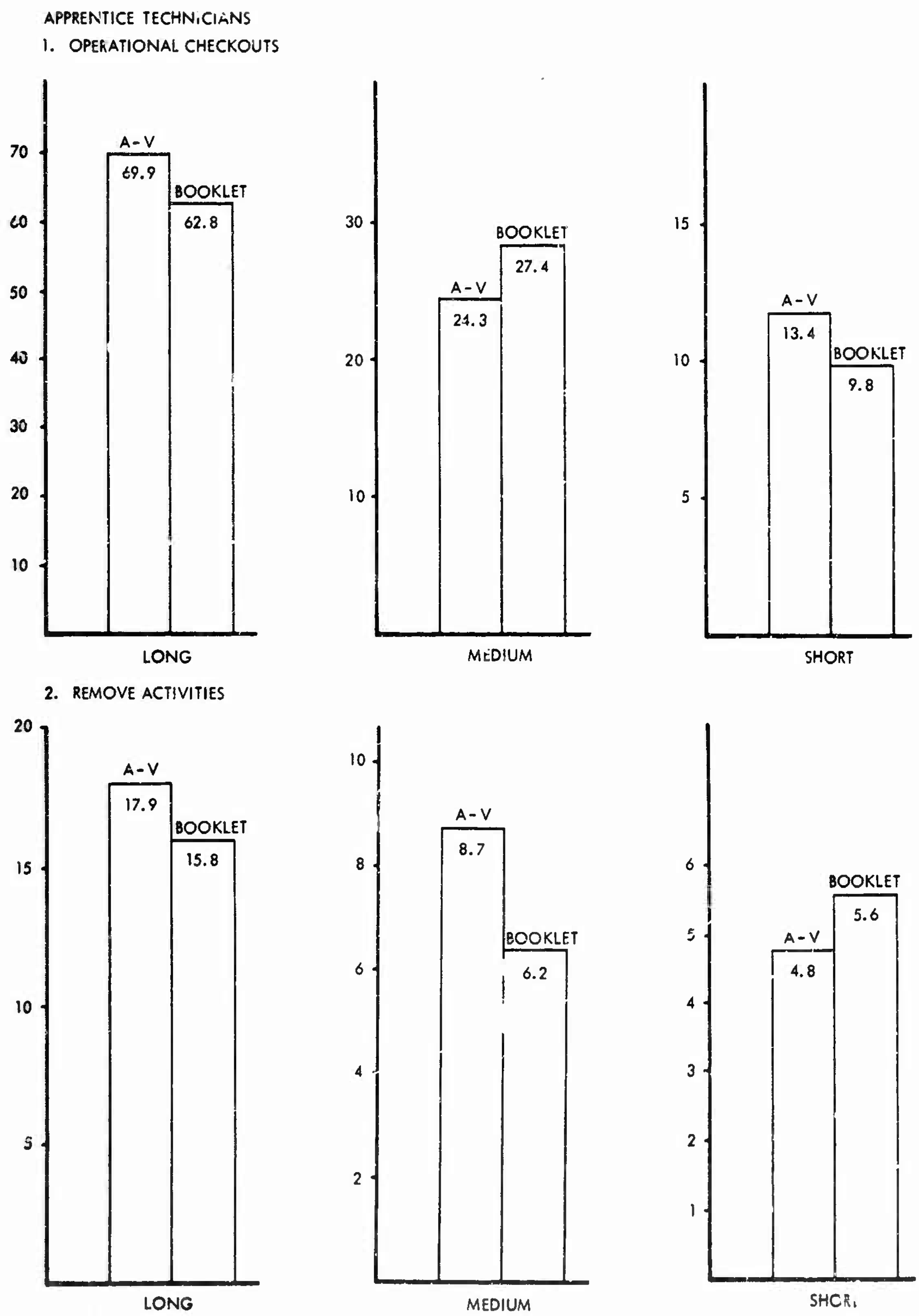

Figure 6-4 PIMO Audio-Visual vs. PIMO Booklets

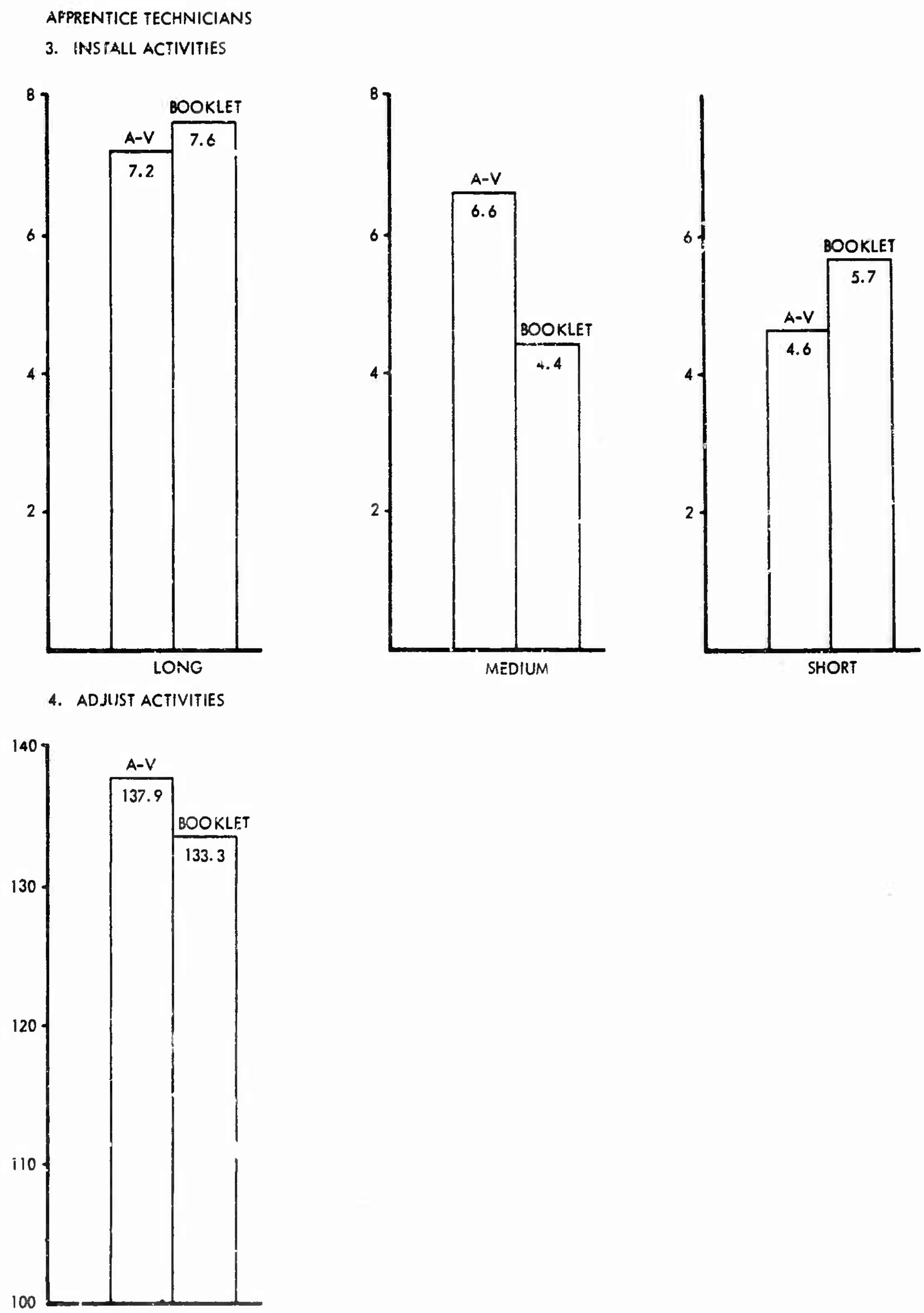

Figure 6-5 PIMO Audio-Visual vs. PIMO Booklet

The graphs shown indicate that in four of the ten cases, the use of the audio-visual mode of presentation resulted in shorter mean times than the use of the booklet. But it should be recognized that the over-all difference of 3%, while still small, is in favor of the booklets.

Table 6-2 reflects the log normal means and the mean differences between the two modes of presentation for the apprentice technicians. One can see that the practical difference of performance times is very low -- in most cases, below four minutes. Only in two cases does the difference of performance time exceed four minutes -- and that is for Adjust activities and long Operational Checkouts. Since there is a definite trend towards improved performance with use of the booklets, coupled with the fact that audio-visual devices require more production resources (time, hardware, etc.) this would lead one to accept booklets as the better presentation mode -- for apprentice technicians, at least.

3. Experienced versus Apprentice Technicians

The test results which contrasted the skill levels indicate that in general, experienced technicians take less time to perform a given maintenance task than apprentices. And, while this holds true for both PIMO modes, it is also obvious from the graphs (see Figures 6-6, 6-7, 6-8, 6-9) that the differences between the performance times of the two groups were not as marked for the audio-visual as they were for the booklet mode. The average time increase equalled 8% with the use of the audio-visual mode, and 33% with the booklet mode. This has significant impact on over-all system performance, since it suggests that it is now possible to employ inexperienced technicians to perform specialized maintenance. This is true, almost irrespective of the presentation mode, but seems to hold more for booklets than for audio-visual presentation. It is interesting to note that in some cases the differences in performance times were almost negligible; in specific: short and medium Operational Checkouts using booklets, medium Install activity using booklets or audio-visual, and medium Remove activities using audio-visual. (See Table 6-3). Here again, one must be cautioned when in drawing con-

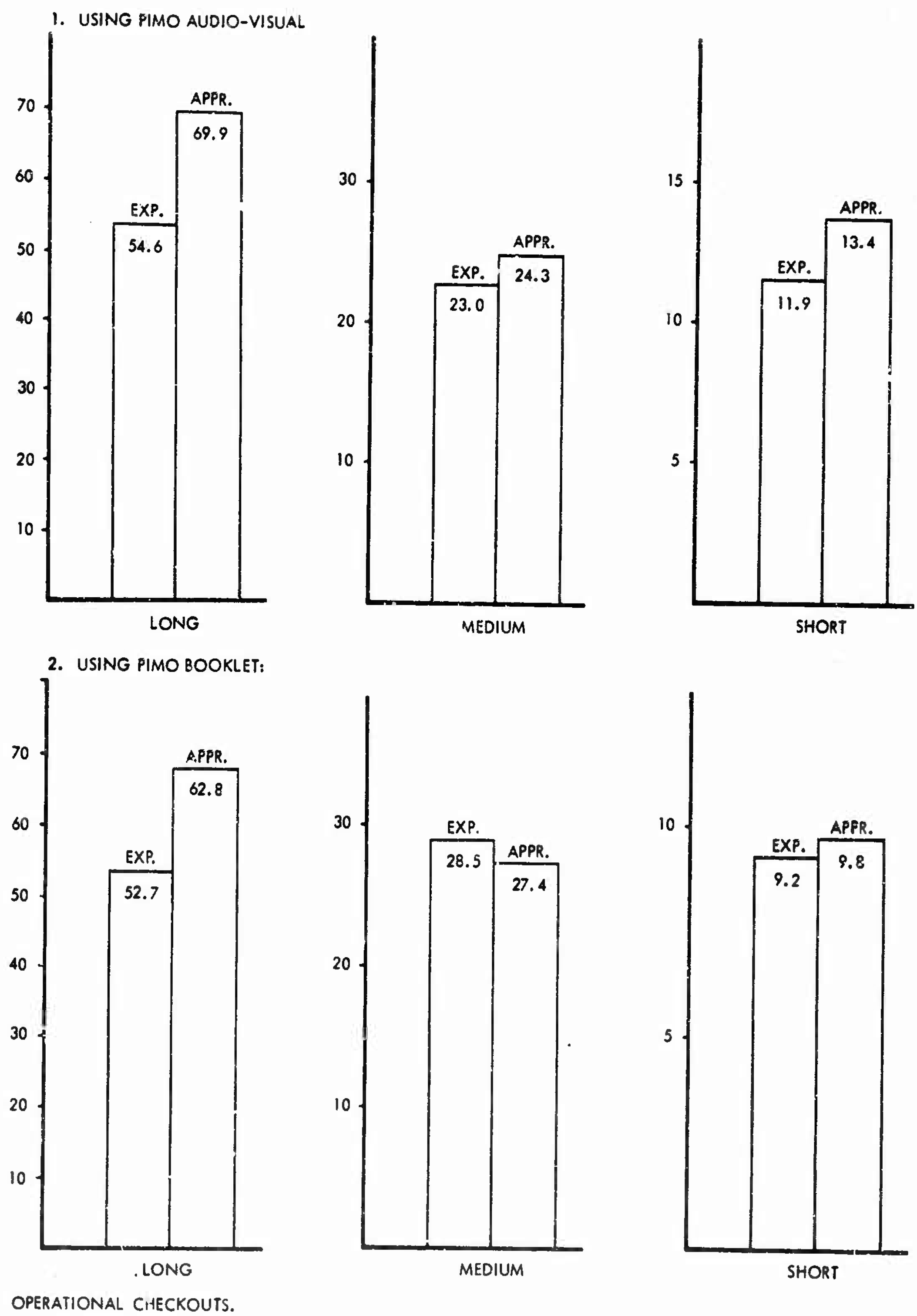

Figure 6-6 Experienced vs. Apprentice

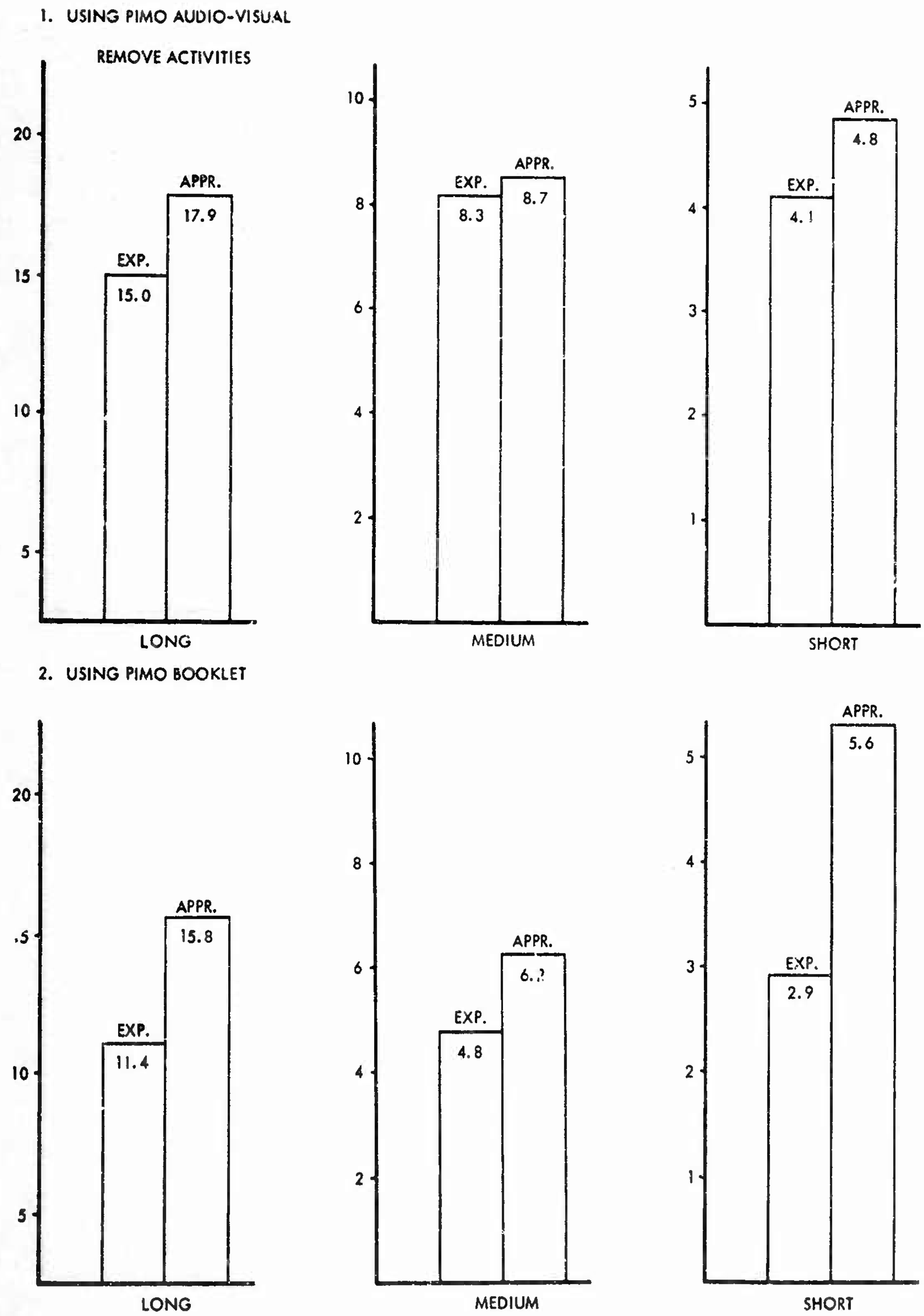

Figure 6-7 Experienced vs. Apprentice Technicians

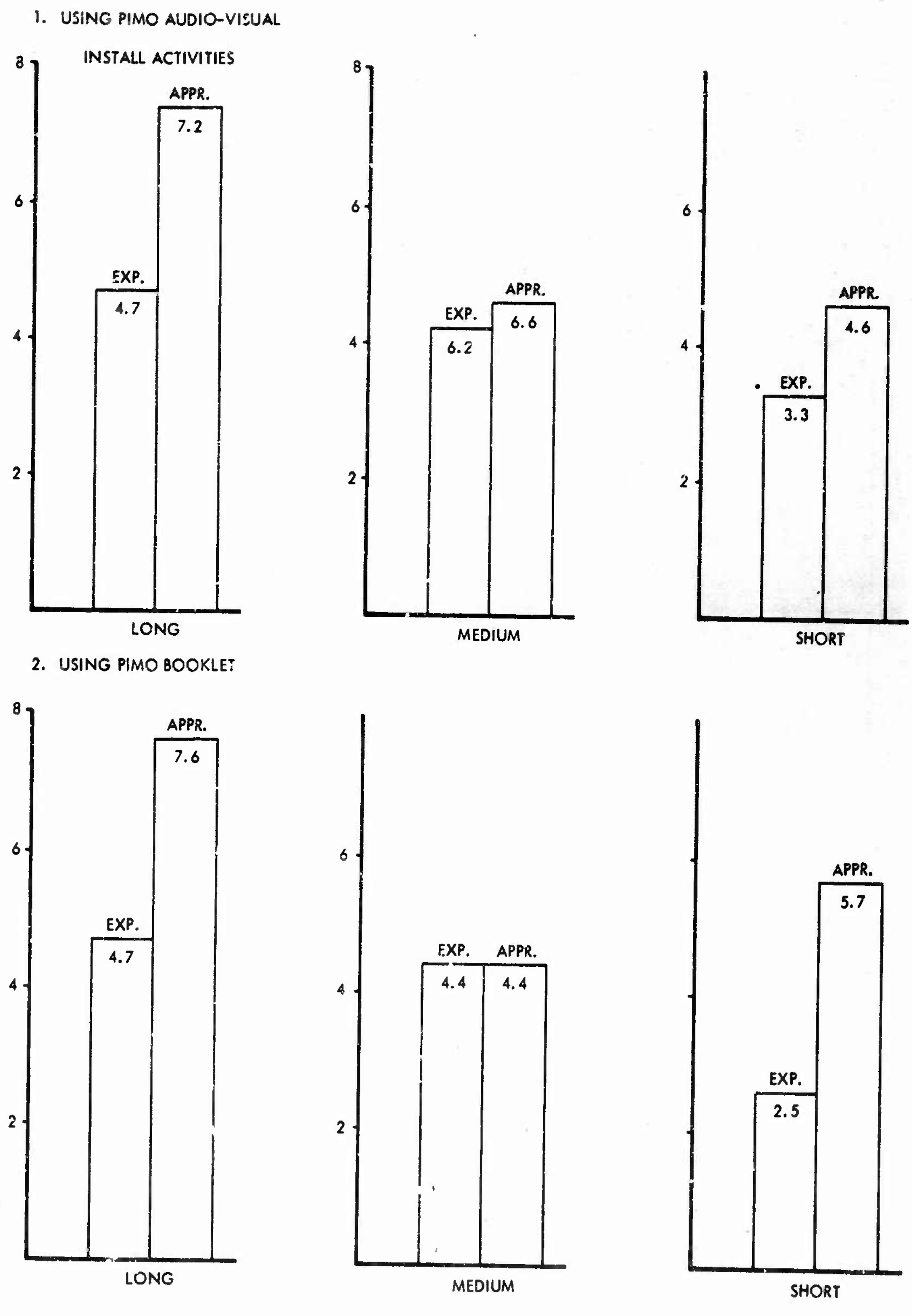

Figure 6-8 Experienced vs. Apprentice Technicians Using PIMO Audio-Visual

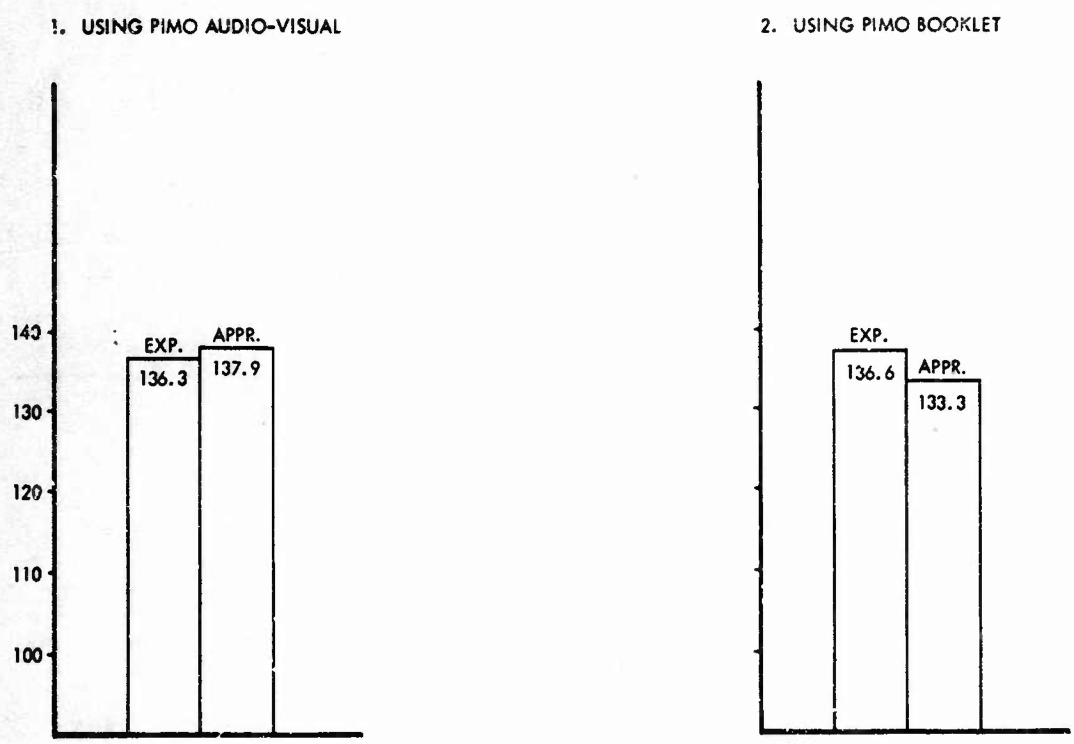

Figure 6-9 Experienced vs. Apprentice Technicians Using PIMO Audio-Visual & Using PIMO Booklet

OPERATIONAL CHECKOUT

	PRESENTATION MODE: LOG NORMAL MEANS IN MINUTES		COMPARISON A-V VS. BOOKLETS	
	A-V	BOOKLET	DIFFERENCE BETWEEN MEANS IN MINUTES	PERCENT DIFFERENCE
LONG	69.9	62.8	-7.1	-10.2
MEDIUM	24.3	27.4	+3.1	+14.8
SHORT	13.4	9.8	-3.6	-26.9

REMOVE ACTIVITIES

	PRESENTATION MODE: LOG NORMAL MEANS IN MINUTES		COMPARISON A-V VS. BOOKLETS	
	A-V	BOOKLET	DIFFERENCE BETWEEN MEANS IN MINUTES	PERCENT DIFFERENCE
LONG	17.9	15.8	-2.1	-11.7
MEDIUM	8.7	6.2	-2.5	-28.7
SHORT	4.8	5.6	+1.2	+25.0

INSTALL ACTIVITIES

	PRESENTATION MODE: LOG NORMAL MEANS IN MINUTES		COMPARISON A-V VS. BOOKLETS	
	A-V	BOOKLET	DIFFERENCE BETWEEN MEANS IN MINUTES	PERCENT DIFFERENCE
LONG	7.2	7.6	+.4	+5.[illegible]
MEDIUM	6.6	4.4	-2.2	-33.3
SHORT	4.6	5.7	+1.1	+23.9

ADJUST ACTIVITIES

	PRESENTATION MODE: LOG NORMAL MEANS IN MINUTES		COMPARISON A-V VS. BOOKLETS	
	A-V	BOOKLET	DIFFERENCE BETWEEN MEANS IN MINUTES	PERCENT DIFFERENCE
	137.9	133.3	-4.6	-3.3

Table 6-2 Within Group Comparisons (Group B, Inexperienced Technicians)

OPERATIONAL CHECKOUT

	AUDIO-VISUAL DEVICE				BOOKLET			
	LOG NORMAL MEANS IN MINUTES		COMPARISON EXPERIENCED VS. INEXPERIENCED		LOG NORMAL MEANS IN MINUTES		COMPARISON EXPERIENCED VS. INEXPERIENCED	
	EXP'D. TECH.	INEXP'D. TECH.	DIFFERENCE BETWEEN MEANS IN MINUTES	PERCENT DIFFER.	EXP'D. TECH.	INEXP'D. TECH.	DIFFERENCE BETWEEN MEANS IN MINUTES	PERCENT DIFFER.
LONG	54.6	69.9	+15.3	+18.6	52.7	62.8	+10.1	+19.2
MEDIUM	23.0	24.3	+ 1.3	+ 5.6	28.5	27.4	- 1.1	- 3.9
SHORT	11.9	13.4	+ 1.5	+12.6	9.2	9.8	+ .6	+ 6.5

REMOVE ACTIVITIES

	AUDIO-VISUAL DEVICE				BOOKLET			
	LOG NORMAL MEANS IN MINUTES		COMPARISON EXPERIENCED VS. INEXPERIENCED		LOG NORMAL MEANS IN MINUTES		COMPARISON EXPERIENCED VS. INEXPERIENCED	
	EXP'D. TECH.	INEXP'D. TECH.	DIFFERENCE BETWEEN MEANS IN MINUTES	PERCENT DIFFER.	EXP'D. TECH.	INEXP'D. TECH.	DIFFERENCE BETWEEN MEANS IN MINUTES	PERCENT DIFFER.
LONG	15.0	17.9	+2.9	+19.3	11.4	15.8	+4.4	+38.6
MEDIUM	8.3	8.7	+0.4	+4.8	4.8	6.2	+1.4	+29.1
SHORT	4.1	4.8	+0.7	+17.0	2.9	5.6	+3.7	+127.6

INSTALL ACTIVITIES

	AUDIO-VISUAL DEVICE				BOOKLET			
	LOG NORMAL MEANS IN MINUTES		COMPARISON EXPERIENCED VS. INEXPERIENCED		LOG NORMAL MEANS IN MINUTES		COMPARISON EXPERIENCED VS. INEXPERIENCED	
	EXP'D. TECH.	INEXP'D. TECH.	DIFFERENCE BETWEEN MEANS IN MINUTES	PERCENT DIFFER.	EXP'D. TECH.	INEXP'D. TECH.	DIFFERENCE BETWEEN MEANS IN MINUTES	PERCENT DIFFER.
LONG	4.7	7.2	+2.5	+53.2	4.7	7.6	+2.9	+61.9
MEDIUM	6.2	6.6	+0.4	+6.4	4.4	4.4	0	0
SHORT	3.3	4.6	+1.3	+39.3	2.5	5.7	+3.2	+128.0

ADJUST ACTIVITIES

	AUDIO-VISUAL DEVICE				BOOKLET			
	LOG NORMAL MEANS IN MINUTES		COMPARISON EXPERIENCED VS. INEXPERIENCED		LOG NORMAL MEANS IN MINUTES		COMPARISON EXPERIENCED VS. INEXPERIENCED	
	EXP'D. TECH.	INEXP'D. TECH.	DIFFERENCE BETWEEN MEANS IN MINUTES	PERCENT DIFFER.	EXP'D. TECH.	INEXP'D. TECH.	DIFFERENCE BETWEEN MEANS IN MINUTES	PERCENT DIFFER.
	136.3	137.9	+1.6	+1.2	136.6	133.3	-3.3	-2.4

Table 6-3 Between Group Comparisons

clusions from these data since they do represent mean times uncorrected for learning. One could safely assume that where little or no practical differences in performance times exist, they would remain so, subsequent to the learning phase. On the other hand, demonstrated elsewhere is the fact that learning does occur. It would be reasonable to assume therefore that one would see a reduction in apprentice performance times, to the point where they begin to approximate the times of experienced technicians.

If one were to assume that these average times were to remain constant, this would not negate the potential effect that is demonstrated here. Not the least aspect of this effect is that maintenance is performed by apprentice technicians, not so much that it is performed in some time which is greater than that for experienced technicians. In a practical sense, when one sees rather large differences between performance times of the two groups -- for example, a long Install activity on audio-visual where the percentage differences are as large as 80% -- this is not an unacceptable increase in performance time. One must consider that it is far superior to having no maintenance at all.

Certainly this is not to suggest that all maintenance be assigned to inexperienced technicians. But one can see clearly that an appropriate strategy for those situations wherein the experienced technician cadre are saturated, would be to assign some of the less critical maintenance activities to the inexperienced technician.

C. STATISTICAL ANALYSIS

1. Basic Study Calculations

Subsequent to the plotting of data for descriptive purposes the analysis-of-variance tests were calculated. Summaries of these tests for each of the four types of maintenance activities appear in Tables 6-4, 6-5, 6-6 and 6-7. As mentioned earlier, the significance stipulated was the .05 level and for a one tailed test.

SOURCE OF VARIATION	SS	df	MS	F RATIO
A (PRESENT. MODE)	.0464	1	.0464	.6946
B (SKILL LEVEL)	.1287	1	.1287	1.9266
C (FUNCTION LENGTH)	22.8893	2	11.4446	171.3263*
AB	.0190	1	.0190	.2844
AC	.4115	2	.2058	3.0808
BC	.0823	2	.0412	.6168
ABC	6.3258	2	3.1629	46.8997*
WITHIN CELL	16.9622	254	.0668	

* Significant at the .05 level for a one-tailed test of significance.

SOURCE OF VARIATION	SS	df	MS	F RATIO
A (PRESENT. MODE)	6.4355	2	3.2178	38.6291*
C (FUNCTION LENGTH)	6.4246	2	3.2123	38.5630*
AC	3.2141	4	.8035	9.6459*
WITHIN CELL	13.4998	162	.0835	

* Significant at the .05 level for a one-tailed test of significance.

F RATIOS

$F_{.95(1,\infty)} = 3.84$

$F_{.95(2,\infty)} = 2.99$

$F_{.95(2,162)} = 3.05$

$F_{.95(4,162)} = 2.43$

Table 6-4 Summary of Analysis of Variance Calculations for Operational Checkout

SOURCE OF VARIATION	SS	df	MS	F RATIO
A (PRESENT. MODE)	.2653	1	.2653	2.7751
B (SKILL LEVEL)	1.9698	1	1.9698	20.6046*
C (FUNCTION LENGTH)	2.0797	2	1.0398	10.8766*
AB	.0965	1	.0965	1.0094
AC	.4851	2	.2426	2.5377
BC	.8442	2	.4221	4.4153*
ABC	.2278	2	.1139	1.1914
WITHIN CELL	33.5432	351	.0956	

* Significant at the .05 level for a one-tailed test.

SOURCE OF VARIATION	SS	df	MS	F RATIO
A (PRESENT. MODE)	.9143	2	.4572	4.1376*
C (FUNCTION LENGTH)	3.2282	2	1.6141	14.6072*
AC	2.5222	4	.6306	5.7068*
WITHIN CELL	32.5960	295	.1105	

F RATIOS

$F_{.95(1,\infty)} = 3.84$

$F_{.95(2,\infty)} = 2.99$

$F_{.95(4,\infty)} = 2.37$

Table 6-5 Summary of Analysis of Variance Calculations for Install

SOURCE OF VARIATION	SS	df	MS	F RATIO
A (PRESENT. MODE)	.9139	1	.9139	11.2688*
B (SKILL LEVEL)	1.1206	1	1.1206	13.8175*
C (FUNCTION LENGTH)	16.3118	2	8.1559	100.5660*
AB	.2910	1	.2910	3.5882
AC	.3291	2	.1646	2.0296
BC	.1822	2	.0911	1.1233
ABC	.0843	2	.0422	0.5203
WITHIN CELL	28.7935	355	.0811	

* Significant at the .05 level for a one-tailed test of significance

SOURCE OF VARIATION	SS	df	MS	F RATIO
A (PRESENT. MODE)	6.4967	2	3.2484	32.1943*
C (FUNCTION LENGTH)	15.1222	2	7.5611	74.9366*
AC	.6594	4	.1649	1.6343
WITHIN CELL	30.7856	305	.1009	

* Significant at the .05 level for a one-tailed test of significance.

F RATIOS

$F_{.95(1,00)}$ 3.84

$F_{.95(2,00)}=2.99$

$F_{.95(4,00)}=2.37$

Table 6-6 Summary of Analysis of Variance Calculations for Remove

Table 6-4 summarizes the calculations of the analysis-of-variance for the Operational Checkout maintenance function. As shown at the bottom, an F-ratio of 3.84 is required for significance with one and 254 degrees of freedom (as shown in some cases); and an F-ratio of 2.99 is required with two and 254 degrees of freedom. Notice that only in three instances do we have an F-ratio significant at the .05 level of higher. In one case we have an F-ratio of 171, which shows an extreme degree of statistical significance, but with no practical significance since it is associated with function length (i.e., short, medium and long). It is fully expected that the differences in function length, as an inherent quality of the maintenance activity, would indeed show significance. However, in the other two cases -- presentation mode by function length interaction, and presentation mode by skill level by function length interaction -- there is practical significance.

What may not appear quite so obvious is the importance of the fact that there is no significance between skill levels. At first glance, since one is normally used to looking for significance, this would appear to be a negative finding. But, closer inspection will reveal that one should normally expect to find a significant difference in performance times between these two groups, since there is a real difference in their experience level. This further reinforces the idea that unskilled maintenance technicians may be assigned to those maintenance tasks heretofore reserved for the qualified technician only. Furthermore, since there appears to be no significance between the two presentation modes, this would support the conclusion that the visual-only, or booklet mode of presentation, would be the more cost effective.

The lower half of Table 6-4 indicates the within group comparison of Group A only using the audio-visual, booklet, and standard operating procedures for long, medium, and short operational checkouts. No comparison is made between these three by three independent variables and the unskilled group, since unskilled maintenance technicians were not allowed to perform maintenance using SOP. Notice also that <u>all</u> elements show significance. Once again, the reader is cautioned to

disregard the significance shown for function length, since this was an inherent characteristic of the test design.

There is, as mentioned before, significance within the main effect of presentation mode. This significance is created primarily from differences in performance times between PIMO and SOP. As described earlier, and as reflected in the bar charts, the mean time to perform maintenance under SOP was shorter than that for maintenance performed under PIMO. Once again this was due to an artifact in the data analysis, since all data were accumulated to produce mean times, and mean times do not reflect the performance of either inexperienced or experienced technicians once they have had an opportunity to acquire learning.

Figure 6-10 reflects the presentation mode by function length interaction for Operational Checkout activities. The large variance exists essentially for long and medium activities, when audio-visual mode is contrasted with booklet. While statistical significance does occur as a consequence of the differences between these means, it can be seen that the practical difference is not enough to warrant the absolute rejection of one presentation mode over the other -- at least not based on mean performance times alone. As mentioned many times earlier, however, when the cost factors are introduced, it becomes obvious that the booklet mode is the more effective.

Table 6-5 is a summary of the analysis-of-variance calculations for the Install maintenance function. The same level of significance for one tailed test was imposed, and the required F-ratios are shown at the bottom of the table. For the 2 x 2 x 3 analysis, there were only three elements of significance: skill-level and function-length main effects, and the skill-level by function-level interaction. Function length significance again is discounted. The significance of the skill-level main effect is important. Contrary to the skill-level main effect for Operational Checkout, the significance here indicates that there is a difference in performance time by the two groups -- experienced and inexperienced

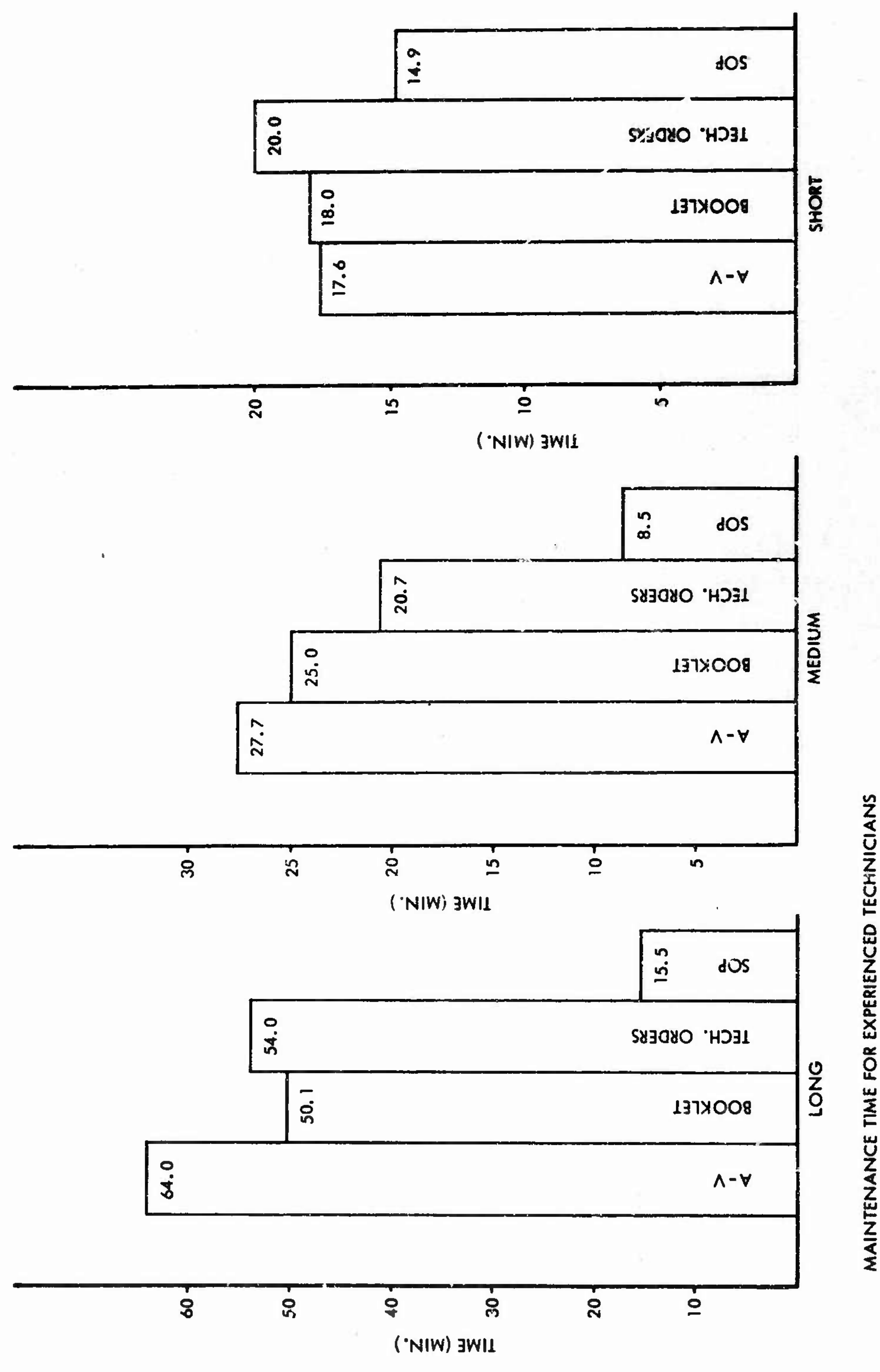

Figure 6-10 PIMO vs. T.O. Pilot Test

technicians. Figure 6-11 plots the skill-level by function-length interaction. It is obvious that the long and short Install activities contribute the major source of variance, with the inexperienced technician taking considerably longer on both of those activities. A satisfactory explanation to account for these differences would be difficult to make, based on the data available. Nonetheless, when one takes a look at the real times involved -- approximately a three minute difference on long Installs and approximately 2-1/2 minutes on the short Installs -- one can see that there is very little practical difference indeed. The small penalty that one might be called upon to pay for the use of inexperienced technicians would be paid back by an over-all improvement in systems effectiveness as a consequence of more aircraft available to accept mission assignments.

The 3 x 3 analysis -- Group A only, contrasting audio-visual with booklet and SOP for long, medium, and short activities -- indicates significance at both main and interaction effects. A review of Figure 6-2 points up an interesting anomaly. For short and medium activities, SOP times are equal to, or lower than, the PIMO performance times. However, with the long Install activity, SOP times become greater than either of the two PIMO presentation modes. This is particularly interesting in light of the fact that here again the over-all means include the learning times. The difference between SOP and A-V times for medium Install activities is almost a factor of three. This would seem at first to rule out the use of PIMO in the A-V mode, but we are describing a real difference of only 4 minutes. It would be safe to assume that the SOP average of 2.3 minutes represents a time fairly close to the physiological limit of performance on these activities. It would also seem reasonable to expect that the performance time for this activity on the A-V or booklet presentation mode would begin to drift toward that level, subsequent to initial learning.

The summary for the analysis-of-variance for the Remove maintenance activity is shown in Table 6-6. Once again, the same significant level

was selected for one tailed test; and the f-ratios required for those significances are shown at the bottom of the table. The elements of significance are: the presentation mode, skill level and function length main effects. There is no significance for the interaction effects. Function length, again, will not be discussed for the reasons mentioned above. Review of Figure 6-1 shows that there is a large contribution made by the differences in performance time between A-V, booklet and SOP for both inexperienced and experienced technicians. It should be noted that the differences in performance times for each of these modes is greater in degree for the experienced and inexperienced technicians. Furthermore, the direction of differences is the same in all cases, except that of short Remove activities.

For apprentice technicians, the difference between A-V and booklet is reversed from that of the experienced technicians. In all other cases, A-V presentation mode requires the longest performance times. The greatest difference in significant performance times is for long Remove activities by experienced technicians -- where the time goes from 7.3 to 15 minutes.

The differences in skill level performance are not as drastic as one might assume from the statistical significance which was achieved. In most cases, less than 2 or 3 minutes represent the difference between experienced and inexperienced personnel performance. The largest difference occurs for long Remove activities using the PIMO booklets, where the experienced personnel perform in approximately 11 minutes, as opposed to the apprentice personnel in approximately 16 minutes. The practical difference between these two times is negligible when considered in light of the over-all system effectiveness.

The 3 x 3 table indicates that there is a significance in the main effect of presentation mode. This is primarily due to the differences noted between the technicians using SOP and either one of the PIMO presentation modes.

The analysis-of-variance calculations performed on the Adjust maintenance function is shown in Table 6-7. Only a 2 x 2 analysis was performed rather than the 2 x 2 x 3, since it was not possible to collect a sufficient number of sample points to adequately perform the larger analysis. There are no statistical significances shown here, but again this in itself has some significance, since it indicates that inexperienced personnel can perform Adjust maintenance functions as well as the skilled. The 3 x 1 table shows significance for the presentation mode main effect, primarily as a consequence of the variance contributed by the differences between PIMO and SOP.

2. Basic Study Summary

In relating the results of the analysis-of-variance tests to the data configurations just described, the following summary may be given.

a. Presentation Modes

While the booklet performance time averages observed during this test were, on the whole, shorter than for the audio-visual mode, the difference was statistically significant only for the Remove activities. This would indicate that the technicians reflected no preferences in the presentation modes, as a function of their performance times. Therefore, it would be safe to assume that one could propose as an operational system, the least expensive of the two modes. The booklet mode -- visual only -- has been demonstrated to be somewhat less expensive in all aspects than audio-visual presentation. Consequently, it is that technique which is recommended in Volume III of this report, Operational System Design.

b. Skill Level

The results of the analysis indicate that apprentice technicians do, in most cases, require more time to perform a given maintenance function than the certified specialists. Those differences,

however, while statistically significant only in the case of Remove and Install activities do represent rather small practical differences. The f-ratios obtained from the analysis-of-variance suggest that no significance may be attached to the differences observed for Operational Checkouts and Adjust activities. This leads to the obvious conclusion: that one can reliably assign inexperienced technicians with PIMO with the reasonable expectation that maintenance could be accomplished within a very small time difference from that of a qualified technician and with no errors.

c. <u>Mann-Whitney U Test</u>

Selected samples were abstracted from the larger data base and subjected to analysis by the Mann-Whitney U technique. It was the purpose of this test to provide an additional measure of validity to the data analysis. In no way did the results of this analysis contradict the apparent trends as evolved from the analysis-of-variance. These tests did show significance in some instances when PIMO presentation modes were compared with the Standard Operating Procedures. The results from this test, together with the high F-ratios derived during the analysis-of-variance, allows a great deal of reliance to be placed upon the inferences drawn.

In the main, PIMO produced longer maintenance times than SOP. It should be pointed out, however, that the field test lasted for only four months, and that the technicians were exposed to this entirely new method of maintenance only for the duration of this test. There are good indications described in a later section that learning effects may have contributed to the observed differences. (These later analyses were made to investigate the learning effects, and to better describe and evaluate any observable trends). When comparing the two PIMO methods, the results of the test show the booklet mode to be more effective

than the audio-visual mode. The observed time differences between the two presentation modes were not evenly distributed across the two groups of technicians. In fact, they were considerably smaller for apprentices than experienced technicians. This would seem to indicate that the audio-visual mode may provide more help to technicians with little experience, than to technicians with a high degree of experience and specialization. Moreover, the same observation seemed to be borne out when the two groups of technicians were contrasted. The experienced group, while generally performing maintenance in less time than the apprentices, did relatively better when they used the books. Stated differently, the differences between the two groups of technicians were smaller with the audio-visual mode of data presentation than with the booklet mode.

3. TSA Evaluation Study

Figure 6-3 is a bar graph which contrasts the mean performance times for troubleshooting with the TSA's and with the standard troubleshooting procedures. The data show that the use of the PIMO troubleshooting manuals resulted in an 11% decrease in troubleshooting time. When tested for significance, (students *t*), it was shown that this was a statistically significant difference. Only experienced technicians were used as subjects in this test, since the troubleshooting aids were designed for them, and it was not possible to employ apprentice technicians. Observed troubleshooting errors were grouped by type. The errors identified are presented in Table 6-7. Errors were discovered in 29.2% of the troubleshooting actions using SOP's, while they were discovered in only 2.5% of the troubleshooting actions using the PIMO TSA's. Equally as significant is the fact that 12.2% of the troubleshooting actions with SOP, as compared to 2.5% of the actions with the TSA's, identified components to be replaced erroneously. This has a large impact, not only on the efficiency with which troubleshooting may be accomplished, but upon the spares consumption rate, which in turn reflects upon the over-all life cycle costs of the larger system.

SOURCE OF VARIATION	SS	df	MS	F RATIO
A (PRESENT. MODE)	.0021	1	.0021	1.2353
B (SKILL LEVEL)	.0021	1	.0021	1.2353
AB	0	1	0	0
WITHIN CELL	.1381	82	.0017	

SOURCE OF VARIATION	SS	df	MS	F RATIO
A (PRESENT. MODE)	.0263	2	.0132	8.25*
WITHIN CELL	.0862	54	.0016	

Sample Randomized Design

F RATIOS

$F_{(1,80)} = 3.96$

$F_{(2,55)} = 4.02$

Table 6-7. Summary of Analysis-of-Variance Calculations for Adjust

4. Special Test

Mention was made in Section V of this volume of a special test conducted at the conclusion of the basic field test. Its primary objective was to compare the PIMO presentation modes with standard Air Force Technical Orders. Performance time and errors were used as the dependent variables. For purposes of this test, a sub-group of apprentice technicians was further divided into two groups. The first group had had no previous experience maintaining the assigned system. The second group had had experience on the assigned system using the PIMO Job Guides. Comparisons between performances with the PIMO Job Guides and Technical Orders indicate that apprentice technicians were able to perform maintenance with the tech orders only after they had repeatedly performed that maintenance, on the same system, previously using the PIMO Job Guides. In fact, the recorded mean times were approximately equal for both cases.

When a comparison was made of the apprentice using PIMO with the specialists using the tech orders, the data indicated that the apprentice performed nearly as well as the specialists. On the other hand, the inexperienced technicians who had no experience with PIMO, in some cases were unable to complete the job without assistance. While these results could not be tested statistically due to the small sample size, they nonetheless demonstrated a very important point already made apparent from the main test: PIMO Job Guides could function as a training device, without subjecting the apprentices to long training periods.

For purposes of this special study, four types of procedural errors were identified. These errors were: 1) Type A -- maintenance step performed either out of sequence or omitted; 2) Type B -- maintenance step performed incorrectly; 3) Type C -- indication called for erroneously interpreted and not correctly obtained; and 4) Type Ω -- maintenance action terminated due to lack of experience or to lack of information. In analyzing these errors, Types A, B, and C were combined,

and Type Ω was treated separately. The primary statistical tests employed in the analysis was χ^2. In other instances, Fisher's Exact Probability Test was used; both tests were held to the 5% level of significance. Table 6-8 presents the data gathered during the special test, and shows a comparison of the apprentice technicians who had prior PIMO experience, with the apprentice technicians who had no prior experience.

Figure 6-10 shows a bar chart comparing the mean maintenance times for experienced technicians under four modes of data presentation: audio-visual, booklet, PIMO, tech orders and standard operating procedures. This is for long, medium and short opcheck maintenance activities. Figure 6-11 contrasts the maintenance time for experienced technicians using tech orders versus apprentices. Figure 6-12 reflects the maintenance times for the two groups of apprentice technicians -- naive and experienced -- when using tech orders, and audio-visual or booklet modes of data presentation. When both groups were assigned T.O.'s, it can be demonstrated that both the A, B, C errors and the Ω errors were significantly greater for those technicians with no prior experience. The obvious conclusion is that PIMO is, in fact, a useful training aid; and that it will enable technicians to perform maintenance more accurately even when PIMO is not used.

Of even greater importance is the suggestion that the apprentice technicians actually make far fewer errors than the experienced technicians (see Table 6-9). This should be taken with caution, however, since the difference cannot be demonstrated to be statistically significant. It is safe to conclude that apprentice technicians after several uses of PIMO are able to perform maintenance as accurately as the experienced technicians when both must perform maintenance using the standard T.O.'s. If the three modes of data presentation are compared -- for the three groups of technicians -- it can be seen that in all cases significantly more A, B, C errors are made with the tech orders, than are made with either the audio-visual or the booklet mode of presentation. Moreover, the apprentice technician commits significantly more Ω errors

	Standard Operating Proecdures	PIMO Trouble-Shooting Aids
Total Troubleshooting Actions	41	40
Troubleshoot, isolated problem, removed and replaced component, system opchecked as bad. Had to retroubleshoot and remove and replace a different component before system opchecked as good.	5	1
Troubleshoot, isolated problem, performed corrective action (non-remove), system opchecked as bad. Had to retroubleshoot and perform additional maintenance on different component before system op-checked as good.	4	0
Troubleshoot but could not isolate problem, opchecked and found bad; retroubleshoot and isolated problem.	3	0
Total Errors	12	1
Percent Errors	29.2%	2.5%

Table 6-8. Troubleshooting Errors Identified During Field Test

	A-V	Booklet	T.O.
Experienced Technicians	n = 30 ABC = 0 Ω = 0	n = 21 ABC = 0 Ω = 0	n = 9 ABC = 16 Ω = 0
Apprentice technicians with prior PIMO experience	n = 39 ABC = 0 Ω = 0	n = 12 ABC = 0 Ω = 0	n = 11 ABC = 13 Ω = 0
Apprentice technicians with no prior experience	n = 17 ABC = 0 Ω = 0	n = 8 ABC = 0 Ω = 0	n = 9 ABC = 49 Ω = 6

Table 6-9 Errors Identified During Special Test

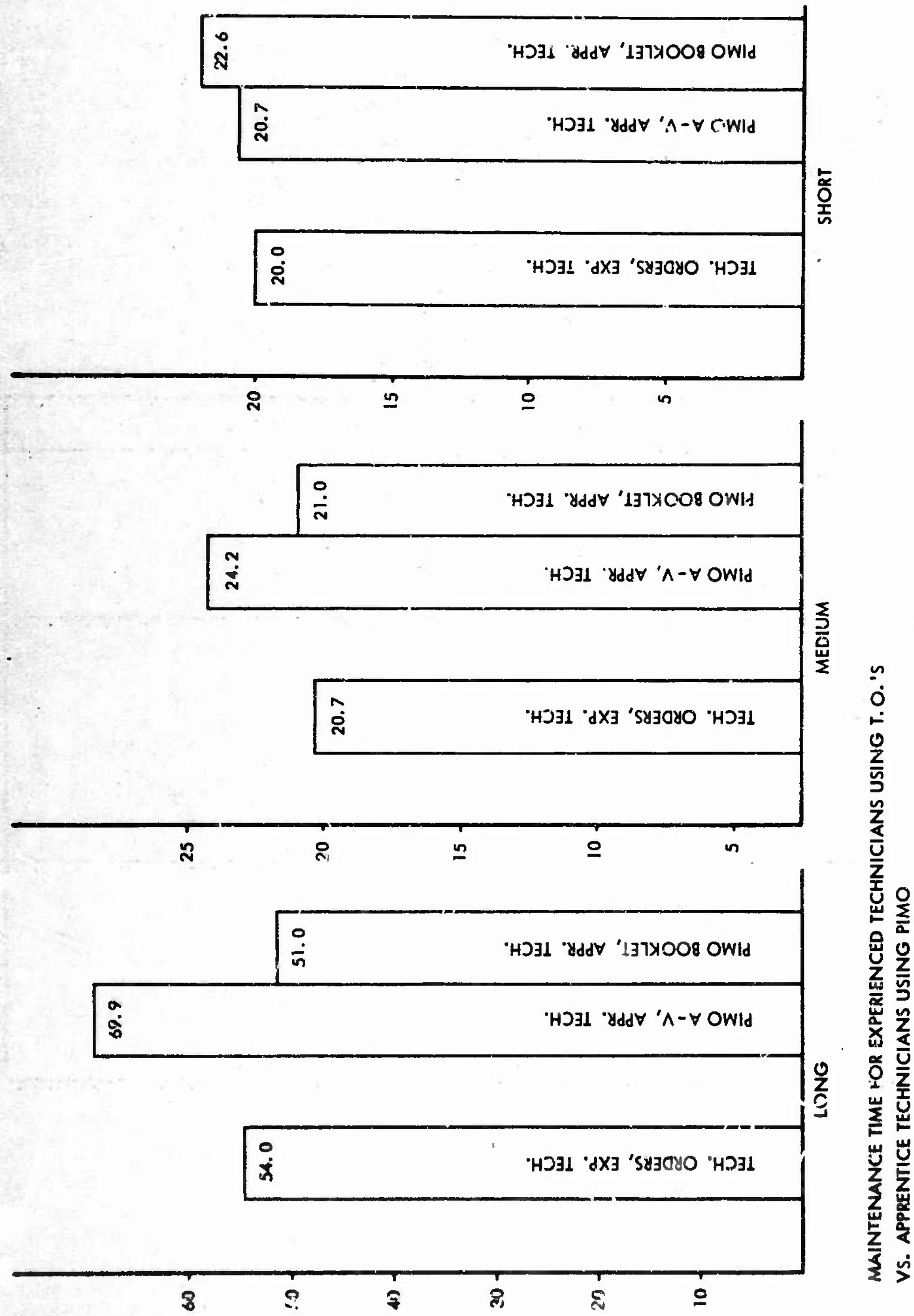

Figure 6-11 PIMO vs. T.O. Pilot Test

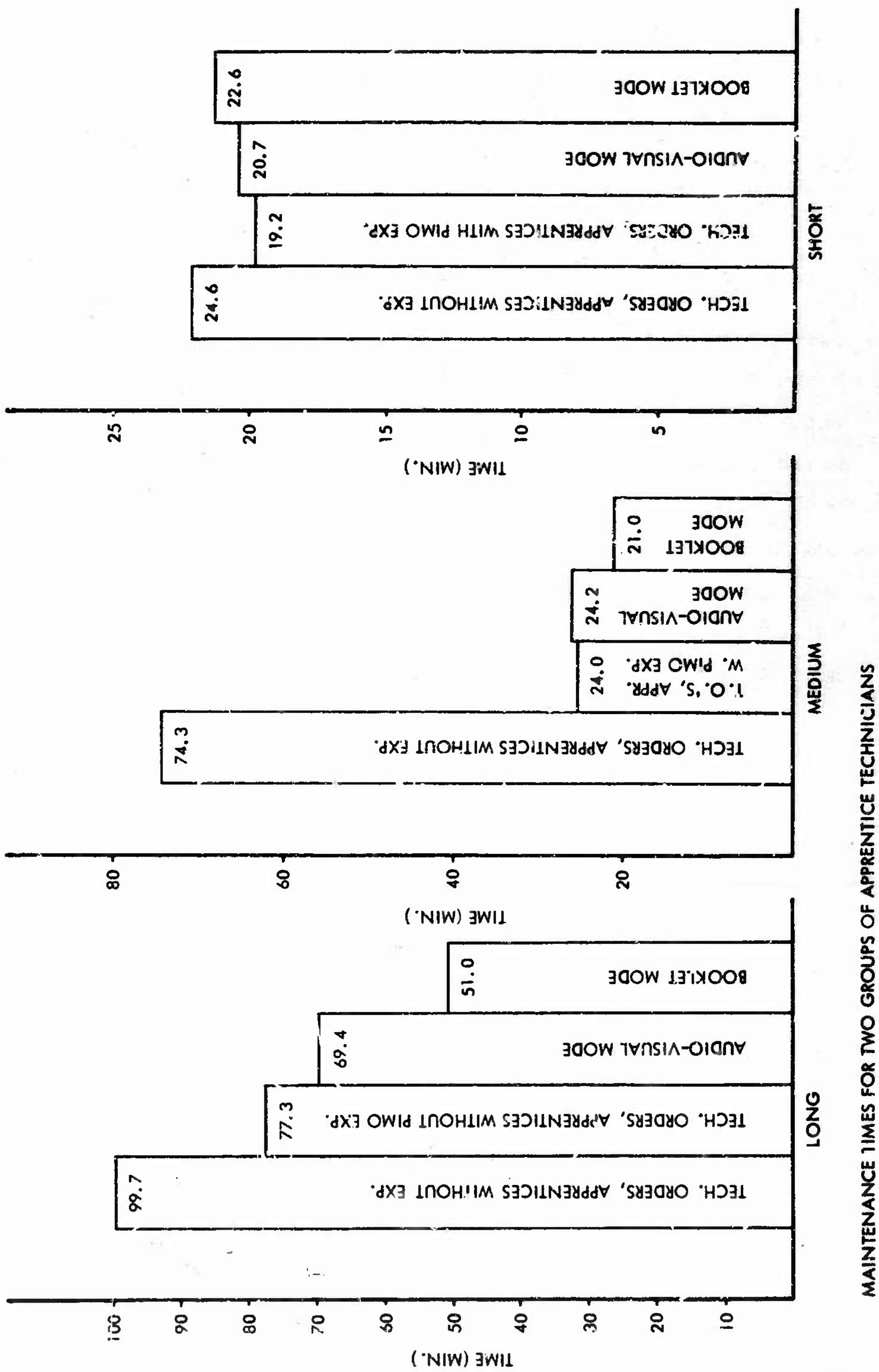

Figure 6-12 PIMO vs. T.O. Pilot Test

under T.O.'s than he made with either audio-visual or booklet mode. These data seem to suggest that almost regardless of experience all technicians who use the PIMO Job Guides can perform maintenance with equal accuracy.

5. Learning Effects

Evidence from both field and laboratory research indicate that in almost every case where motor skills are involved, learning does take place. In order to better evaluate the degree to which learning may have been acquired by the subjects of this test, and the subsequent impact this learning may have had on their over-all performance, it was decided to develop learning curves from the collected data. The learning curves were developed for both experienced and inexperienced personnel, and are expressed as a percent of the average SOP time. The data are presented by the number of successive actions on the same activity -- first time performed, second, third, etc. Two curves are presented; one shows the data as it was computed directly. This curve, although showing a classical learning situation, is somewhat erratic due to the random variation in data. The second is derived from the first, and represents a smoother version. There is good reason to believe that this curve is more congruent to one which depicts the actual learning process. These curves are shown in Figures 6-13 and 6-14. Inspection of these curves shows that there did exist a definite learning effect when the PIMO Job Guides were employed. For example, the first action by an experienced technician using PIMO took approximately 2.6 times as long as it did an experienced technician using his normal means of maintenance. However, his performance time dropped rapidly until at the end of the eighth performance he was performing the maintenance using PIMO in less time than he took using SOP. In a like fashion, the first action by inexperienced technicians was shown to take approximately 2.5 times as long as an experienced technician using his Standard Operating Procedures. Here too, the performance time progressively decreased until approximately the twelfth repetition where it was shown to take the inexperienced technician approximately

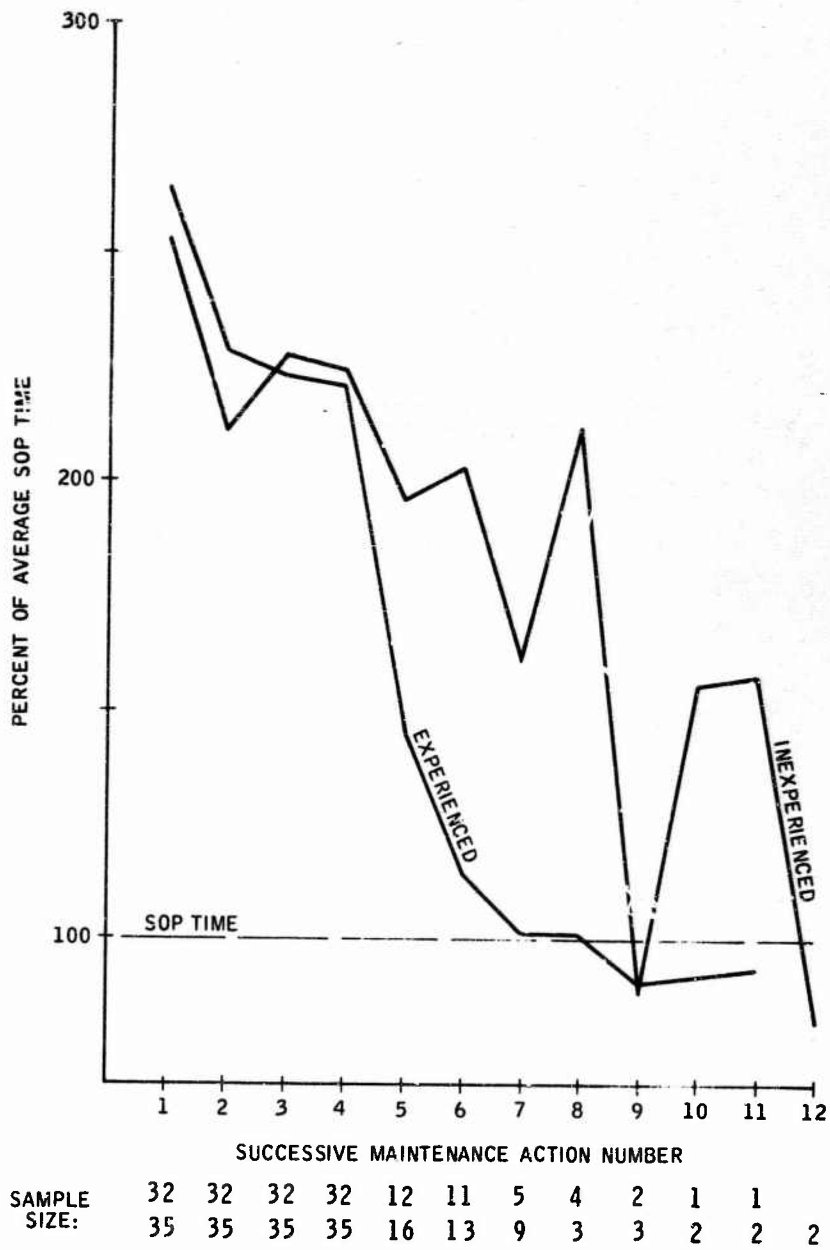

Figure 6-13 Learning Curve

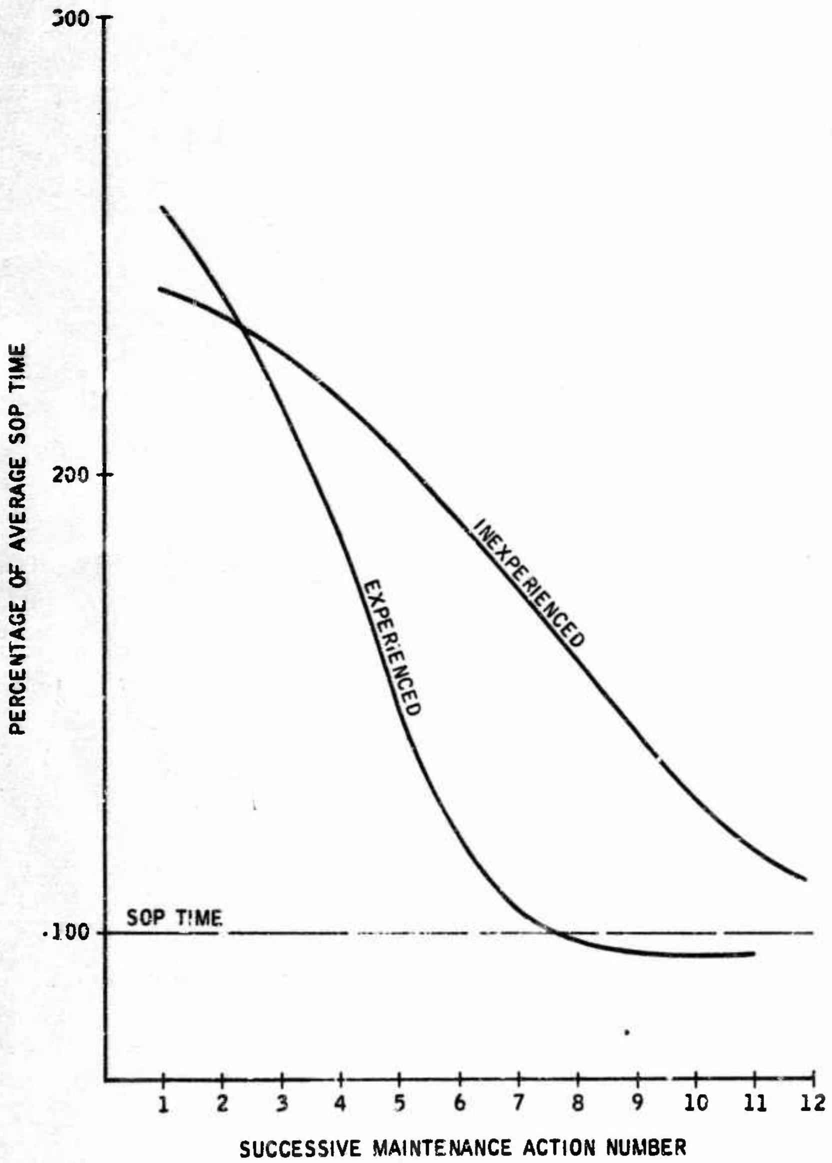

Figure 6-14 Smoothed Learning Curve

1.2 times as long as the experienced. While no data are available past this point, it is, nonetheless, believed that TIF continues to decrease with experience, until such time as the inexperienced technician performs at a rate of the experienced technician.

In effect, there are really two learning effects coming into play here. One is the learning process associated with the use of PIMO materials and the second is the learning effect as a consequence of repeating maintenance many times on specific hardware. The experienced technicians, we can safely assume, were already trained on the hardware and were performing maintenance which indicated only the learning effect due to PIMO. On the other hand, the inexperienced personnel, untrained in the particular system, reflect in their learning curves both effects -- the learning of PIMO, and the learning of hardware.

3. <u>Time Change Matrix</u>

The time change matrix (see Figure 6-15) reflects for each pair of maintenance actions -- for identical man and activity -- the average percentage of time change by mode. The matrix does not give values which would be capable of developing a learning curve; rather it intends to assess the relative learning between the various modes and experience levels, and to add validity to the learning curves already developed. Two matrices are presented: one for the experienced, one for the inexperienced technician. They are presented in the form of a 3 x 3 and a 2 x 2 contingency table for the experienced and inexperienced technicians, respectively. For both technicians the percentage change from booklet to booklet is greater than that from audio-visual to audio-visual. This would seem to suggest that learning may be faster with the booklets than with the audio-visual. However, since it was mentioned previously that there were two learning effects coming into play, it is impossible to identify the contribution of each to the percentage change. Therefore, even though learning with the booklet may appear to be faster, it is not known if the learning of the PIMO methods, the hardware, or both is really the major contributor.

The data also seem to indicate that learning for the experienced technicians is greater than that for the inexperienced technicians. This would follow logically, since it can be assumed that the differences in the learning rates are due in part to the learning of the hardware by the inexperienced technicians.

EXPERIENCED TECHNICIANS

		2ND ACTION		
		A-V	BOOK	SOP
1ST ACTION	A-V	-6.0%	-27.1%	-62.0%
	BOOK	+71.7%	-14.2%	-32.0%
	SOP	+142.8%	+41.4%	-2.0%

INEXPERIENCED TECHNICIANS

		SECOND ACTION	
		A-V	BOOK
FIRST ACTION	A-V	-17.8%	-19.0%
	BOOK	+28.0%	-19.7%

Figure 6-15. Time Change Matrix

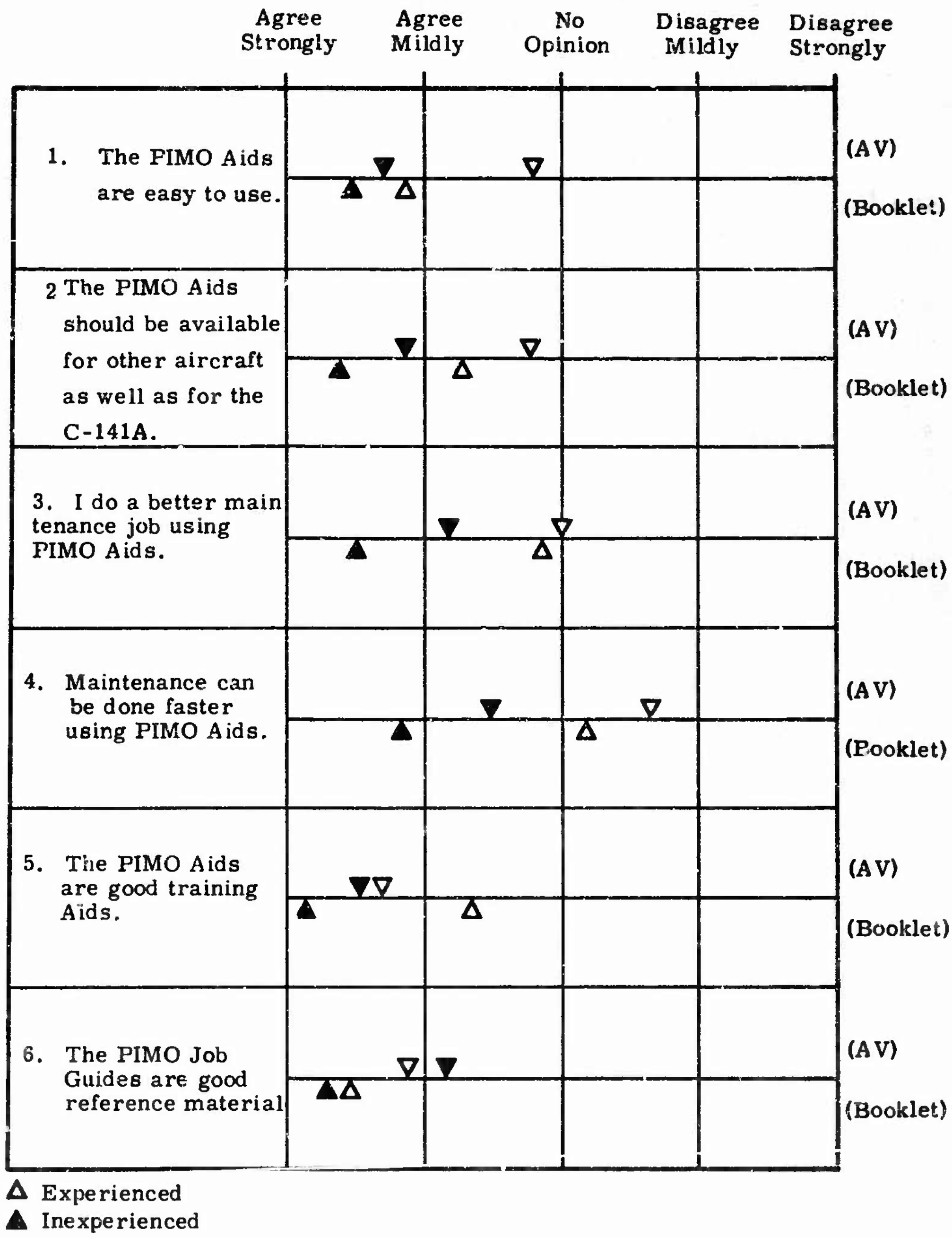

Figure 6-16. Impact of PIMO

D. USER ACCEPTANCE

In order to determine the reaction of the user toward PIMO Job Guides and TSA manuals an attitude questionnaire was developed. This questionnaire was administered to all subjects twice during the course of the field test. The first administration occurred at the halfway point, when presentation modes were changed. This questionnaire, slightly modified to account for the differences in experience, was administered again at the conclusion of the field test.

Originally, it had been planned to analyze the data through the use of non-parameteric statistics, such as χ^2. Inspection of the data revealed that it was distributed in ratios so large that it made inferential statistical analysis unnecessary. The questionnaire items are separated into two broad categories. The first is that of the subject's demographic data, which recorded his age, skill level, length of time in service, etc. The second broad category is that of attitudes of PIMO acceptance, and is composed of both multiple choice attitude questions and open-ended questions. The questionnaire was administered under rigidly controlled circumstances in the field, and it is believed that the data gathered from this questionnaire is highly reliable.[1] Each maintenance technician at the conclusion of the test had used both the PIMO modes of presentation a large number of times. Therefore, the questionnaire responses should have been based upon intimate familiarity with the PIMO methods.

Table 6-10 shows the demographic characteristics of all PIMO subjects. The median age for the subjects was twenty-three years. Sixty-eight and nine-tenths percent of the technicians were 5-levels, and 14 percent of the technicians were 3-levels. This left a remainder of 17 percent for 7- and 9-levels. The length of time in service for C-141A maintenance tended to distribute itself bimodally. Over 59 percent of the technicians had been in the Air Force for more than a year, while

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1 While tests of this nature are highly reliable, their validity may not be great as quantitative tests.

a. Age of Technicians

16 - 20 years	17.3%	
21 - 25 years	48.7%	
26 - 30 years	10.5%	Median age - 23 years
31 - 35 years	10.2%	
36 and over	13.3%	

b. Skill level of Technicians

3-level	14.1%
5-level	68.9%
7- and 9-levels	17.1%

c. Length of time technician has been maintaining C-141A's

1 - 6 months	20.9%
7 - 12 months	19.8%
Over 12 months	59.3%

d. Education

1) Experienced Technicians
33 percent had some college while the remainder had finished high school.

2) Inexperienced Technicians
20 percent had some college, 13 percent had some trade school, the remainder had finished high school.

Table 6-10 Demographic Characteristics of Subjects

over 20 percent had been in service less than 6 months. This distribution in no way was allowed to color the data taken during the basic test, since a balanced design was used.

One of the significant questions asked in this questionnaire was whether or not the technicians considered the PIMO aids useful. The responses to these questions are presented on Table 6-11, and are listed according to length of time the technicians have been performing maintenance on the C-141 aircraft. In addition, the question is broken down into the various characteristics of PIMO, such as troubleshooting aids, job guide index, input conditions, etc.

Almost irrespective of length of time in service, the troubleshooting aids were rated as useful. It seems to follow a trend that the less time in service the technician had, the more useful he thought it was. Eighty-two percent of those technicians in service 6 months or less specified that they felt the troubleshooting aids were useful. Only 72-1/2 percent of technicians in service over a year felt that the troubleshooting aids were useful. Nonetheless, this does represent a significant number of technicians. Approximately three-fourths of them felt that the troubleshooting aids were useful.

Maintenance instructions also rated extremely high. Here, over 84 percent of the technicians in service less than 6 months, and almost 94 percent of the technicians in service between 6 months and a year, rated the maintenance instructions useful. The only attribute of the PIMO format which fell below 50 percent, was "Input Conditions". This would seem to say that the input conditions were felt to be not as useful as the other characteristics. But, half of any given number of maintenance technicians still represents a large part of the maintenance force.

In all cases, the technicians in service on C-141A's for over 12 months rated the PIMO aids as somewhat less useful than those technicians in service for less than 12 months. This is not surprising since as the

Question	Length of Maintenance	Useful	Not Useful
Troubleshooting Aids	1 - 6 months	82.0%	18.0%
	7 - 12	79.5	20.5
	over 12	72.4	27.6
	Total	75.3	24.2
Job Guide Index	1 - 6 months	70.9%	29.1%
	7 - 12	77.2	22.3
	over 12	65.8	34.2
	Total	69.1	30.9
Input Conditions	1 - 6 months	44.0%	56.0%
	7 - 12	51.0	49.0
	over 12	43.2	56.3
	Total	44.8	55.2
Prepare for Activity	1 - 6 months	64.3%	35.7%
	7 - 12	59.1	40.9
	over 12	48.5	51.5
	Total	52.4	47.6
Maintenance Instructions	1 - 6 months	84.6%	15.4
	7 - 12	93.8	6.2
	over 12	73.8	26.2
	Total	78.5	21.5

Table 6-11 Usefulness of PIMO Response

experience level increases, the usefulness of any maintenance aid decreases. It is interesting to note, however, that the technicians in service between 7 and 12 months rated three out of the five PIMO characteristics as more useful than those in service for less time. One reason offered, is that the newer rated C-141A technicians are probably 3-levels who have a limited experience in performing maintenance on that aircraft. Therefore, their use of PIMO was as part of, or in lieu of, an OJT training environment.

Several questions were designed to obtain the technician's reactions to statements concerning PIMO aids. The responses to these questions were converted to a nominal scale, assuming equal intervals between the categories. The results were than averaged and plotted graphically as shown in Table 6-12. In general, it can be seen that the summary of responses all reside on the positive side of the scale. In two cases -- question, "I do not do a better maintenance job using PIMO aids", and question, "Maintenance can be done faster using PIMO aids" -- the responses were clearly undifferentiated and constellate around the "don't-know" portion of the scale. In no case do the subjects indicate that they strongly disagree. One can conclude from this that there would be very little, if any, resistance to the use of these aids were they implemented as an operational system. As discussed earlier in this report, simply having a new and more efficient technique for formatting technical data is not sufficient to introduce positive changes in over-all system effectiveness. It goes without saying that the technicians must use the data in order for its effectiveness to be felt.

One item in the questionnaire asked for responses concerning whether or not the technicians felt the Air Force was heading in the right direction by developing PIMO. The results of this question are shown in Table 6-13. The responses to this question were favorable, with almost 70 percent of the technicians responding that PIMO was a step in the right direction. Again, it should be noted, that as the experience level increased, the positive attitude towards PIMO decreased. This is not to say, however, that the attitude ever became negative, since

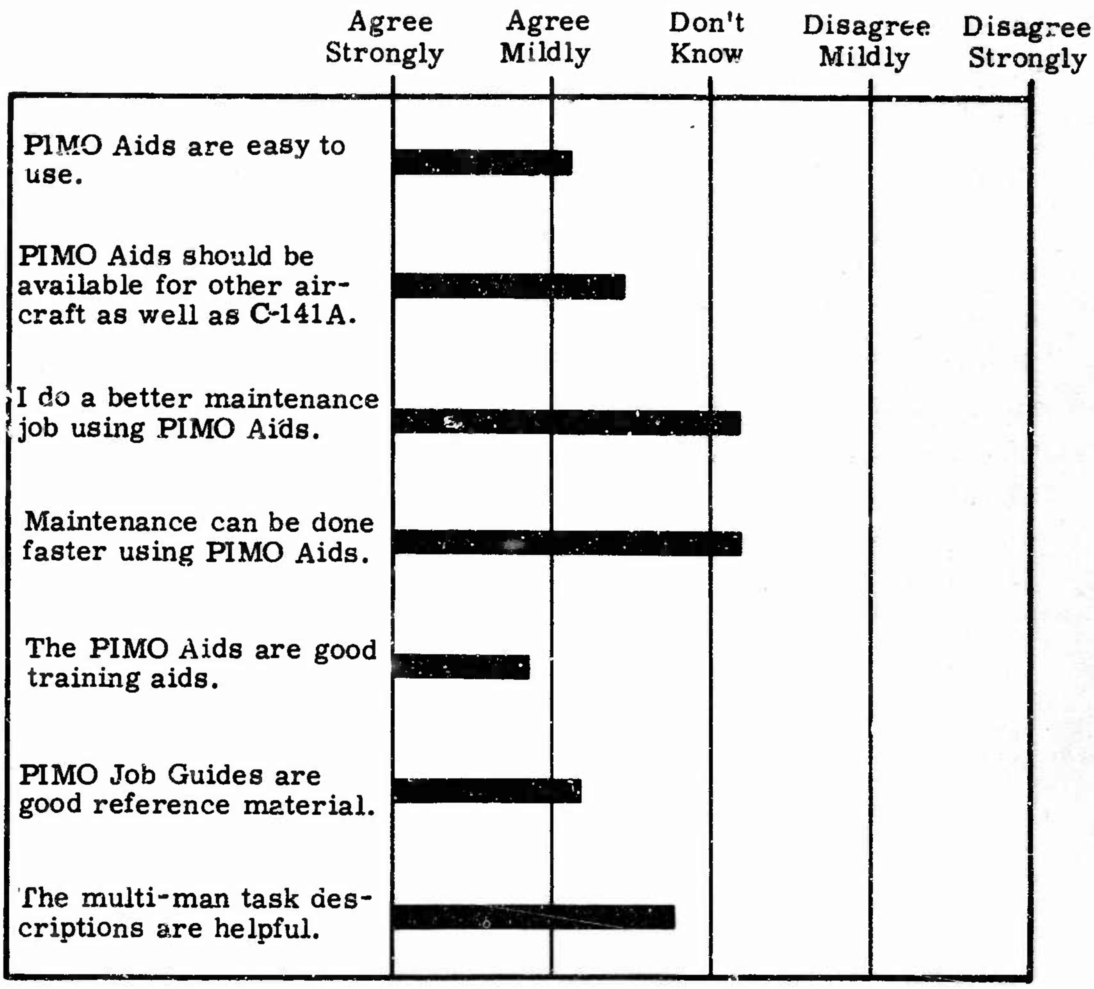

Table 6-12. Technicians reactions to PIMO job guides.

Length of Maintenance	Right Direction	Wrong Direction
1 - 6 months	83.5%	16.5%
7 - 12 months	68.2%	31.3%
Over 12 months	65.5%	34.4%
Total	69.5%	30.5%

Table 6-13 Direction of the Air Force with PIMO

almost 66 percent of the technicians with over 12 months of service responded that they felt the PIMO technique <u>was</u> a step in the right direction.

The technicians were also requested to state their likes and dislikes of the PIMO booklets. Each respondent was allowed to indicate a maximum of five likes and dislikes. The number of responses from these items were totaled, averaged, and are presented in Table 6-14. Several characteristics of the formats were provided as dimensions: for example, size, weight, level of detail, organization, language, index, etc. One interesting note is that the technicians tended to disagree on their responses. For instance, for the "likes", the technicians gave an average of 2.73 responses; but only slightly above half of the respondents were positive about the size, which was the highest ranking "like". On the other hand, for the "dislikes" the responses were more uniform. The highest ranking "dislike" received a response from slightly over one-fourth of the respondents. Finally, it should be noted that the technicians indicated 77 percent more "likes" than "dislikes".

Subsequent to the completion of the field test, the second questionnaire was administered. In this questionnaire, the technicians were asked which mode of presentation, if any, they would use for maintenance jobs which occurred at different frequencies. The results of this question are presented in Table 6-15. Using the binomial test of significance at the .05 level of significance, it was determined that there was a preference for the PIMO mode of presentation by both skill levels, for all jobs which occurred with infrequent regularity. Surprisingly, approximately one-half of the technicians indicated a preference for PIMO Guides for those jobs which occur with greater regularity.

Given that the PIMO method of presentation was preferred, the skilled technicians indicated a preference for the booklets over the audio-visual device for those tasks which occur frequently or even occasionally. For tasks which occur very seldom, there was no preferential difference

Characteristic	Like	Dislike
Size	.54	.09
Weight	.30	.05
Level of Detail	.18	.22
Technical Accuracy	.15	.23
Illustrations	.43	.11
Organization	.24	.18
Job Preparation Information	.16	.18
Language	.20	.11
Ease of Use	.38	.08
Index	.13	.18
Other	.02	.06
Total	2.73	1.54

Table 6-14 Technician's Opinion of PIMO Characteristics

Frequency	Group	PIMO Audio Visual %	PIMO Booklets %	Either PIMO Presentation %	Neither PIMO Presentation %
1 - a job done very frequently	Experienced	0	50	50	50
	Inexperienced	0	60	60	40
2 - a job done occasionally	Experienced	7	71	78	21
	Inexperienced	0	100	100	0
3 - a job seldom done	Experienced	29	64	93	7
	Inexperienced	0	100	100	0
4 - a job never done	Experienced	50	50	100	0
	Inexperienced	13	87	100	0

Table 6-15

between the booklets and the audio-visual modes. For unskilled technicians, on the other hand, there was a significant preference for the booklets over the audio-visual device for all tasks, regardless of their frequency of occurrence. This tends to support the other evidence, that the technicians who have used the PIMO method of presentation do prefer and would use that mode when it was available. It also tends to indicate that, in general, there is a preference for the booklet over the audio-visual device. Here again, this result falls in line with the conclusions and recommendations for the Operational System as outlined in Volume III. As noted earlier, a) since there were little or no significant differences in performance times for the A-V versus the booklet mode of presentation, b) and since technicians do seem to indicate a preference for booklets, c) and further, since the booklet mode represents a less expensive system to initiate and to operate, the booklet modes evolve as the recommended technique.

Other questions on the second questionnaire asked the technicians to state their agreement/disagreement with several statements concerning the possible impact of the PIMO aids. Such questions as, "The PIMO aids are easy to use", "I do a better maintenance job using PIMO", "The PIMO aids are good training aids", were included. Graphical results of the questions were obtained by applying a numerical value to each possible response, with the underlying assumption that equal intervals between the responses existed. The values obtained in this manner were then averaged and plotted graphically. A statistical analysis was performed which used only the direction of the responses without regard to magnitude. The tests used were the Fisher Exact Probability Tests and the Binomial Test of Significance -- both at the .05 level of significance. The results of the responses to these questions are plotted in Figure 6-15. Included are the responses for both modes of presentation, and for both groups, (i.e., skilled and unskilled). It can be seen that the unskilled technicians as a group gave a more favorable response than the skilled technicians -- in all cases save three. Of these three cases, two responses were identical to the

skilled personnel, and one was in a more unfavorable direction. These data disclose that the unskilled personnel significantly recognized the usefulness of PIMO than do the skilled personnel. Moreover, the data show that both groups gave a favorable response significantly more often than an unfavorable response. If these six questions can be considered as approximate descriptors of the PIMO concept in general, then one can infer that both levels of personnel are significantly favorable in their attitude towards the concept; and that in addition, the unskilled personnel are significantly more favorable than are the skilled personnel. Here again, the responses to the booklet were in a direction more favorable than the responses to the audio-visual. This supports the data taken from the earlier questions and the discussion presented earlier in this volume. Last, it should be noted that the questions which received the most favorable responses were those concerned with PIMO as a training aid and as reference material. Both groups of subjects showed strong agreement to these statements, but seemed to prefer, in both instances, the booklet over the A-V presentation mode.

Since two questionnaires were issued, it was possible to perform an analysis to determine if the technicians' attitudes towards the PIMO concept changed with time. All questionnaires administered at the halfway point were matched to the final questionnaire by the identical respondent. The differences in the responses between the two questionnaires to key questions were recorded and analyzed (questions 1 through 6 of Section IV were the key selected questions). It was found that responses to the questions on the final questionnaire were significantly more favorable than were the questions by the identical technicians on the first questionnaire. This would indicate that the user's attitude towards the questionnaire became more favorable as they became more familiar with the concept, through use.

In re-questioning the subjects concerning the usefulness of the PIMO aids, a shift was indicated towards the useful side. Table 6-16 shows that for the inexperienced technicians, 100 percent agreed that the job guides were useful for all maintenance activities except troubleshooting.

QUESTION	EXPERIENCED TECHNICIANS		INEXPERIENCED TECHNICIANS	
	Useful	Not Useful	Useful	Not Useful
Troubleshooting Aids	100%	0%	N/A	N/A
Job Guides -- for Remove/Install	73%	27%	100%	0%
Job Guides -- for Checkout	91%	9%	100%	0%
Job Guides -- for Adjust	100%	0%	100%	0%

Table 6-16 Before and After Responses

Here, of course, the question was not applicable since inexperienced technicians were not used as subjects in the troubleshooting aids effectiveness study. On the other hand, the experienced technicians agreed 100 percent, that the troubleshooting aids were useful; and except for Remove and Install, agreed almost 100 percent that the job guides were useful. (For Remove and Install, 73 percent agreed that they were useful).

When the technicians were asked again if they felt that PIMO was a step in the right direction on the part of the Air Force, the responses were as follows: 80 percent of the experienced group agreed and 100 percent of the inexperienced group agreed that this was the right step. One can conclude from this, that not only do the technicians feel PIMO Job Guides -- as they have experienced them -- were useful in a personal sense, but that applied to all Air Force aircraft systems, the job guides would provide a substantial support in maintenance activities.

The technicians were again given an opportunity to rate their likes and dislikes of certain characteristics of the PIMO format. These characteristics included size, weight, level of detail, language, illustration and organization, as examples. The questions were weighted according to response and the values were averaged for each group of technicians. The results of this analysis are shown in Table 6-16. The higher the number, the greater the response in the direction of "like". Of particular interest is the comparison between the responses of the unskilled technicians as to what they liked least about the audio-visual and booklet size. Table 6-17 shows that size was least liked about the audio-visual presentation for unskilled technicians, The third and fourth highest values for both levels of technician was booklet size. Stated more simply, this shows that the size of the booklet was one of the better features for its mode, while the size of the A-V device was one of the poorer features for its mode.

Lastly, a section of the questionnaire contained open-ended questions for completion by the subjects. It was felt that this technique would

QUESTION		GROUP	Size	Weight	Level of Detail	Technical Accuracy	Job Preparation Information	Language	Illustration	Organization	Other
BOOKLET	Like Most	Experienced	1.64	.14	.72	.14	.72	.43	1.36	.36	.00
		Inexperienced	1.69	.77	.46	.54	.15	.33	1.15	.85	.00
	Like Least	Experienced	.00	.00	1.14	1.35	1.36	.50	.29	.79	.14
		Inexperienced	.00	.00	.85	.92	1.31	.54	.23	.31	.15
A-V	Like Most	Experienced	.83	.42	.25	.17	.75	1.17	1.58	.83	.00
		Inexperienced	.07	.00	.29	.86	.93	1.28	1.71	.85	.00
	Like Least	Experienced	1.00	.50	.67	.67	.25	.58	.25	.42	.92*
		Inexperienced	2.28	1.43	.78	.21	.29	.28	.14	.21	.21*

*Generally, the inability to repeat individual frames in the A-V device.

Table 6-17. Technician Preferences

provide valuable insight into aspects of the user's feeling of acceptance or rejection that was heretofore untapped. Sincc questions of this type are difficult to categorize and to summarize, it was felt that selected responses typical of those received should be presented wholly as they were taken from the questionnaire itself. They are loosely organized by skill level.

1. <u>Skilled Personnel</u>

"I think it would be good in a training program."

"PIMO is no better or worse than the present T.O. system. If, as in the case of hydraulic systems, the program had not had so many obvious errors it would have been better received."

"I feel the program was very helpful and interesting. The company representatives were capable, willing and I feel they did themselves and the Air Force a <u>job well done</u>".

"PIMO is a very good aid for a unskilled man (Booklet & A-V), a skilled man profits more from the troubleshooting aids than A-V or booklet. If I ran into position where I needed a reference I would like to be able to have a booklet instead of a tech order."

"It was good for training purposes but A-V was too slow and bulky."

"I feel that PIMO aids, such as the organization troubleshooting aids and booklets, can be used to increase maintenance efficientsy. It is also an aid in 3 level training. I only wish that we could have been able to use the aids, in our more complex sys."

"Illustrations could be more clear."

"The guides are written in a maintenance mans language and is easily understandable."

"I believe PIMO aids should definitely be used for training purposes and for jobs a specialist may never have done before."

"I like the PIMO booklets. I think the A/V units are not as convenient to use as the books. The A/V units would be more helpful in training than actual working procedures."

"PIMO would be a very good training aid for the unexperienced mechanic in a specific field."

"PIMO is adequately reduced in size for the booklets but a useable A/V device should be smaller with repeat capabilities for sound and video. The aids are approaching the solution to bulky, poorly written, difficult to follow technical orders and utilization of a system such as PIMO is, in my opinion, a definite improvement over prevailing system."

There were three responses of "No comment."

2. Unskilled Personnel

"The booklets are very handy light weight and easy to use. The detail or technical accuracy of a few jobs needs revising. The A/V's are to heavy and cumbersome and there is no way of backing up a frame. This is much needed. Besides these few things I think PIMO is a real good system."

"That the PIMO aids are easy to understand good to use for maintenance."

"Audio-vis. aids are slightly bulky to carry for a long distance and are incapable of instent replay. The booklet is easy to understand and work with. I feel that the PIMO aids are excellent for maintenance but for training in over all systems training, they do not present enough information to get through their tests in training."

"The PIMO aids do not show some important items that should shown to people who are not familiar with a certain system. I think the booklets are better than Audio-Visual because they are

easier to carry and easier to understand."

"They are easier to use than T.O.'s. They are also lighter and easier to handle."

"PIMO booklets seem to be very good training devices and are very easy to use. I think A/V device would also make a good training aid, but to me seem much harder to use than the booklet."

"I think the booklets are almost perfect except some of the wording is wrong or misleading. Either booklet or A/V would be an excellent training aid for tech school or upgrading to 5 level."

"They were easy to understand. For this 3 level they were good training aids. I did not know any thang about 141's before I cam into PIMO. PIMO inabled me to perform actions which I could not otherwise do."

"PIMO aids are very useful. Everything very clear."

"The booklets are good and need little improvement, if any. The A/V are good but need a good deal of refinement. They are too large and in some cases the verbale task is too long for the unskilled man to grasp."

There were five responses of "No comment".

In summary, it is fairly obvious that the technicians were positively inclined toward the PIMO format. This was true at least by proportions significantly greater than half of those who were users. In almost no instance was there a negative reaction to the guides. If the results of these questionnaires can be accepted as valid -- the reliability has certainly been demonstrated in the matching responses of the two applications of this questionnaire -- then one can safely assume that given the opportunity, a maintenance technician would need little or no encouragement to employ PIMO. This is extremely important when considered in light of the empirically observed use of standard tech data. In only about five percent of the cases do

technicians currently employ the standard technical orders. This is not to say that PIMO would be used, if it were available, to any larger degree, But certainly if the over-all maintenance system were to change in the direction as suggested in Volume III of this report -- that is, toward the employment of lesser skill levels -- then it becomes important to have technical orders which not only can provide the information in a useful manner, but in a way which is found acceptable by the user himself.

Stated in another way, it makes little sense to employ lower skill level technicians to perform maintenance, given supporting tech data, if, he is reluctant or resistant to the use of that tech data. It has been said, that if pressure were applied to the technician, he would employ tech data. This certainly is open to question. It is true that one might, through insistence, achieve the state wherein technicians took the tech data with them to the job site. But this is not to ensure that the data would be consulted by the technician. To paraphrase an old proverb, "You can lead a technician to data, but you can't always make him use it." Responses to the open ended questions seem to indicate a genuine like for the technical data. For instance, one technician wrote that he felt that the guides were written in a maintenance man's language and were easily understood. Another technician commented that he felt the PIMO Job Guides were easier to use than the standard tech orders and were both lighter and easier to handle. These responses are not surprising, in light of the effort that went into the generation of a glossary of terms derived directly from the field maintenance technicians. Finally, if the Air Force decides to implement the PIMO formatting on a system-wide or Air Force-wide basis, there appears to be little or no problem in generating acceptance of these new tech orders on the part of the maintenance technician.

E. SYSTEM EFFECTIVENESS RESULTS

The field test indicated that the PIMO technique of data presentation will, in fact, produce a positive change in C-141 maintenance procedures. The observed effect of PIMO on the maintenance parameters was: 1) PIMO will reduce the maintenance error rate, 2) PIMO will enable lesser skilled maintenance technicians to perform those functions formerly performed by more skilled technicians, and 3) PIMO may increase the time-in-function, particularly for the inexperienced technician. This last parameter will cause a negative change in effectiveness measures since it would take longer to perform maintenance functions. This is true only with the data as they were presently observed, but, as mentioned so many times earlier, these data represent the mean times for all performances, including the performance which occurs very early in the training/learning cycle.

The first effect will beneficially impact the over-all systems effectiveness, because fewer errors will result: a) in fewer reworks of the maintenance for malfunction correction, and b) fewer instances in which malfunctioning aircraft are discovered in preflight inspections, either causing mission delay or requiring aircraft substitution. The second effect will be beneficial since it will provide a greater pool of personnel from which maintenance technicians may be drawn. To fully understand the impact of these parameters upon the over-all systems effectiveness, it was decided to exercise the AMES model and review the results. Data supplied to the model came from, in most cases, the PIMO field test. Time-in-function maintenance data, for example, was derived in this way. The time-in-function used for the nominal case was that observed for the skilled technicians when using SOP's.

The time in-function data for the PIMO AMES runs were derived from the unskilled technician using PIMO data. It was assumed that shop

repair functions would not be affected by PIMO, and in this way the same skilled personnel and the same time-in-function were used in both the nominal and PIMO run for shop repair functions. The specific data input were as follows:

1. The model simulated aircraft operations covering a 100-day period for a base that had 20 operational aircraft.

2. The simulated base was assigned 362 maintenance technicians who performed scheduled and unscheduled maintenance both on aircraft and in the shop.

3. Twenty systems were defined on the aircraft, with each system having some number of components.

4. The component failure rate and repair characteristics were determined from 66-1 historical data, generated from C-141 maintenance history.

5. During simulation, 434 missions were flown. The mission demand and characteristics were determined by a Monte Carlo technique and were based upon historical C-141 data taken from the F-1 forms.

6. The probability of a maintenance error, by designated type, in the system, was determined from a detailed analysis of the 66-1 data.

7. Other input data, such as schedule inspection, characteristics, pre- and postflight characteristics, abort rate, and shop procedures, were determined from published Air Force documents, field interviews, and field observations.

Two approaches to the analysis of the effect of PIMO upon the C-141A system characteristics were taken. The first approach was to deter-

mine the impact upon operational characteristics of the inclusion of PIMO into all on-aircraft unscheduled maintenance.

The second approach was to determine the optimum reduction in maintenance personnel possible when PIMO was incorporated into all unscheduled maintenance -- with the proviso that the operational characteristics would be no worse than are currently experienced.

The operational characteristics chosen for study were: total number of mission delays, total aircraft hours and maintenance function, and percent of time the aircraft were operationally ready. The reader should be cautioned, that the AMES model is a mathematical representation of the real system, and as such it was designed to be highly representative of that system and sensitive to the same effects that occur in that system. However, it was not designed to be an exact representation of the real system. In fact, it would be almost impossible to develop a simulation model which would be exhaustibly congruent to anything as complex as aircraft operations on a given Air Force base. Therefore, it should be remembered that some of the simulation outputs -- particularly those developed as a nominal case -- may differ somewhat from those actually observed in the field. This does not, however, invalidate the results. On the contrary, it indicates that the AMES model results should be viewed in terms of their <u>relative</u> merits, rather than their absolute merits.

Exercise of the AMES model itself consisted of a series of simulation runs. Each run consisted of 20 aircraft over a 100-day period. Derivation of the nominal case from the AMES model consisted of 3 runs, with the only change that of a random-feed input to the model. Three runs were made in order to reduce the run-to-run variance. The average of the three runs was then used to determine the nominal performance.

The exercise of the AMES model with the PIMO data base, consisted of a series of runs with those previously stated modifications in the input data bank.

1. Results of AMES Model Run

Figure 6-17 shows the effect of PIMO implementation on the number of mission delays parameter. For purposes of the model runs, a mission delay was defined as any mission that was unable to depart within 3-1/2 hours from the time of the initial mission demand. Since the model is so designed that the preflight inspection does not begin until a mission is demanded, the 3-1/2 hours normal delay between mission demand and a mission departure was felt to be comparable to actual operations. It should be emphasized that the mission delays as identified by the AMES model were only those which were maintenance related. Primarily, this is because it seemed relevant and because the model was unable to simulate delays due to other causes, such as cargo, flight crews, weather, etc.

Within the AMES model, an aircraft may be delayed due to any mechanical failure regardless of its magnitude. In actual operations, on the other hand, only certain equipment failures are considered crucial enough to delay an aircraft mission. If the malfunction is minor, often the aircraft will depart with the existing malfunction. From this, it can be seen that the number of departure delays, as a consequence of the AMES model run, will be greater in most instances than those actually experienced in the field.

Inspection of Figure 6-17 shows that if PIMO's ability to reduce error rate is disregarded (0% reduction in errors), the benefits of low-skilled personnel being able to perform skilled maintenance produces sufficiently fewer delays to more than offset the additional time-in-function required to perform such maintenance. Then, as the maintenance error rate is reduced, significant improvements in over-all system performance is obtained. For example, at the 50% reduction in troubleshooting, corrective action and operational check errors, the AMES model indicates that mission delays would be reduced by approximately 50%. As an aside, the PIMO field test indicates that the PIMO Job Guides will reduce maintenance errors by significantly more than 50%. In fact, no maintenance

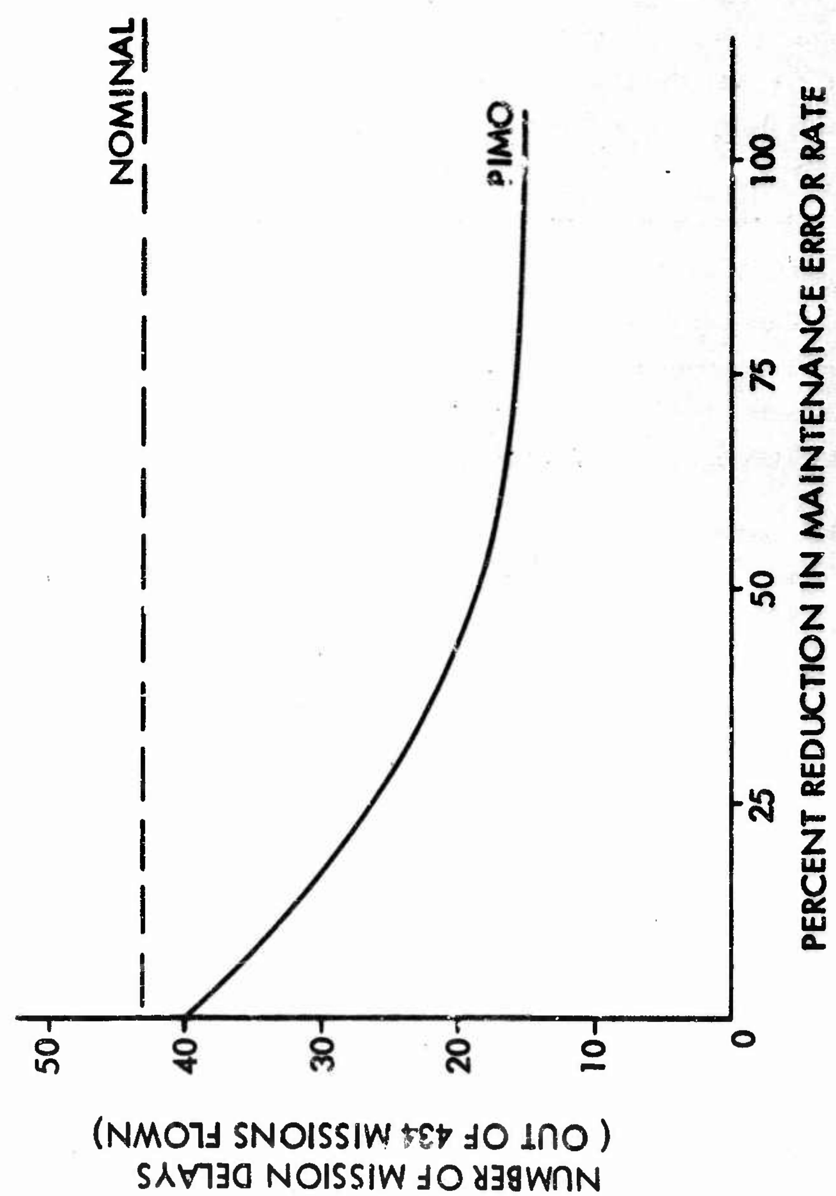

Figure 6-17 Effect of PIMO Upon Mission Delays

errors were observed when technicians used PIMO. This is not to say that no errors would occur in a non-test situation; therefore, if these data were discounted, one could reasonably expect between 80-90% reduction in errors. At the 75% level of reduction in maintenance errors, the number of mission delays is reduced by approximately 65%. At this point the curve has begun to level out, and when it reaches the 100% level of error rate reduction, the number of mission delays is still reduced by approximately 65%.

2. Impact on Unscheduled Maintenance

The effect of PIMO on total aircraft hours and unscheduled maintenance is shown in Figure 6-18. This figure reflects only the time in unscheduled maintenance at the home base. Moreover these figures do not include preflight, postflight, scheduled inspection times, or time for TCTO changes. They do include the time the aircraft are in NORS.

The same conclusions may be drawn from this curve as were drawn from the previous curve, almost without exception. For a 50% reduction in maintenance errors, the total aircraft hours in unscheduled maintenance is reduced by 37%. This continues until the 100% level of reduction in errors is reached, where a maximum of 44% improvement in unscheduled maintenance is seen.

The consequence of this effect is such that one can see that there would be necessarily fewer maintenance technicians required or fewer parts stores required, or both. In addition, since the aircraft would be available more hours for operational mission assignment, a reduction in life cycle costs for the aircraft would be realized.

3. Percent of Time Operationally Ready

Figure 6-19 shows the effect of PIMO on the operational readiness state of the aircraft. These figures reflect both the time away from home base and the time at the home base, for which the aircraft are designated as operationally ready. Operational readiness is defined

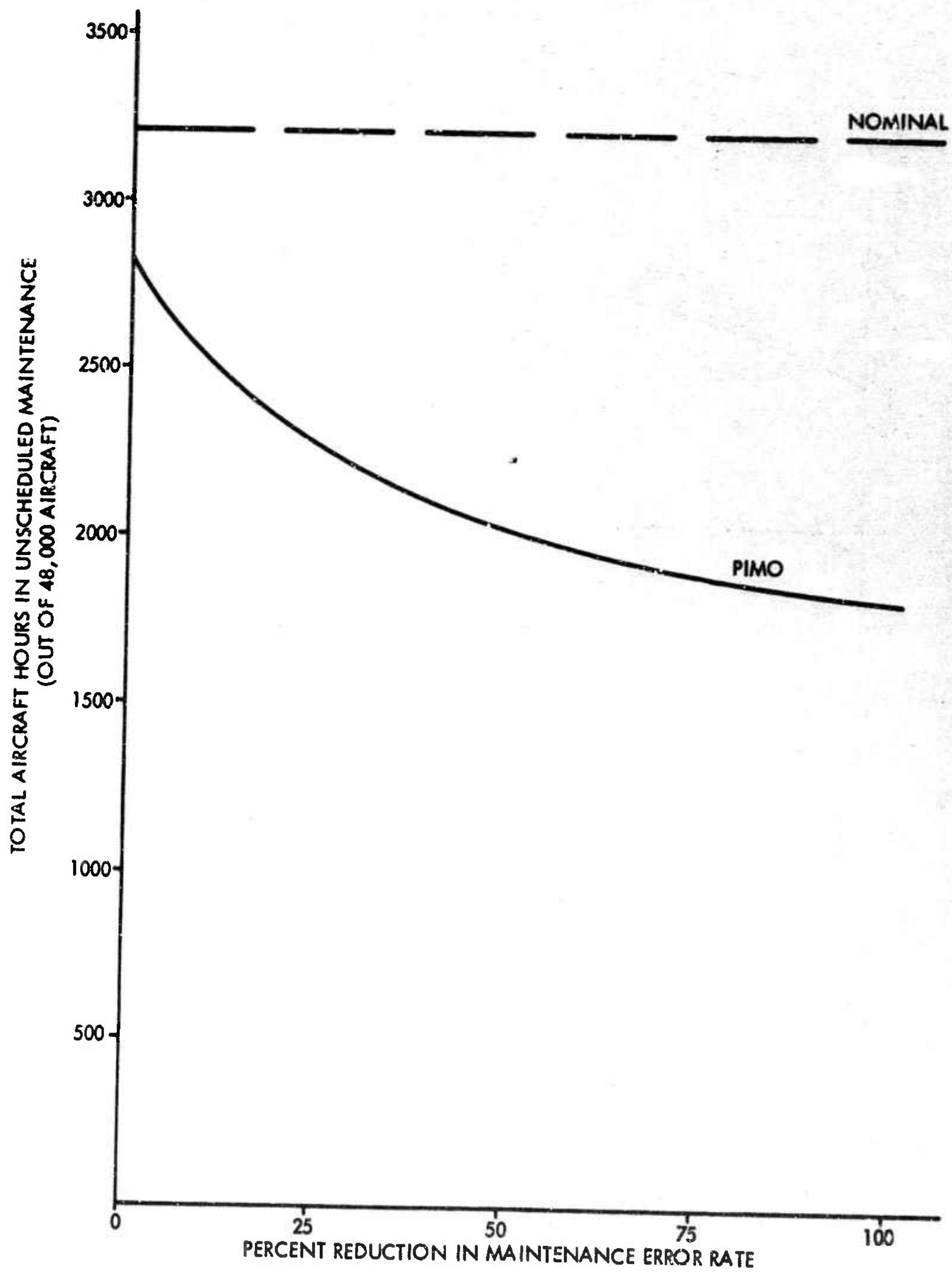

Figure 6-18 Effect of PIMO Upon Aircraft Hours in Maintenance

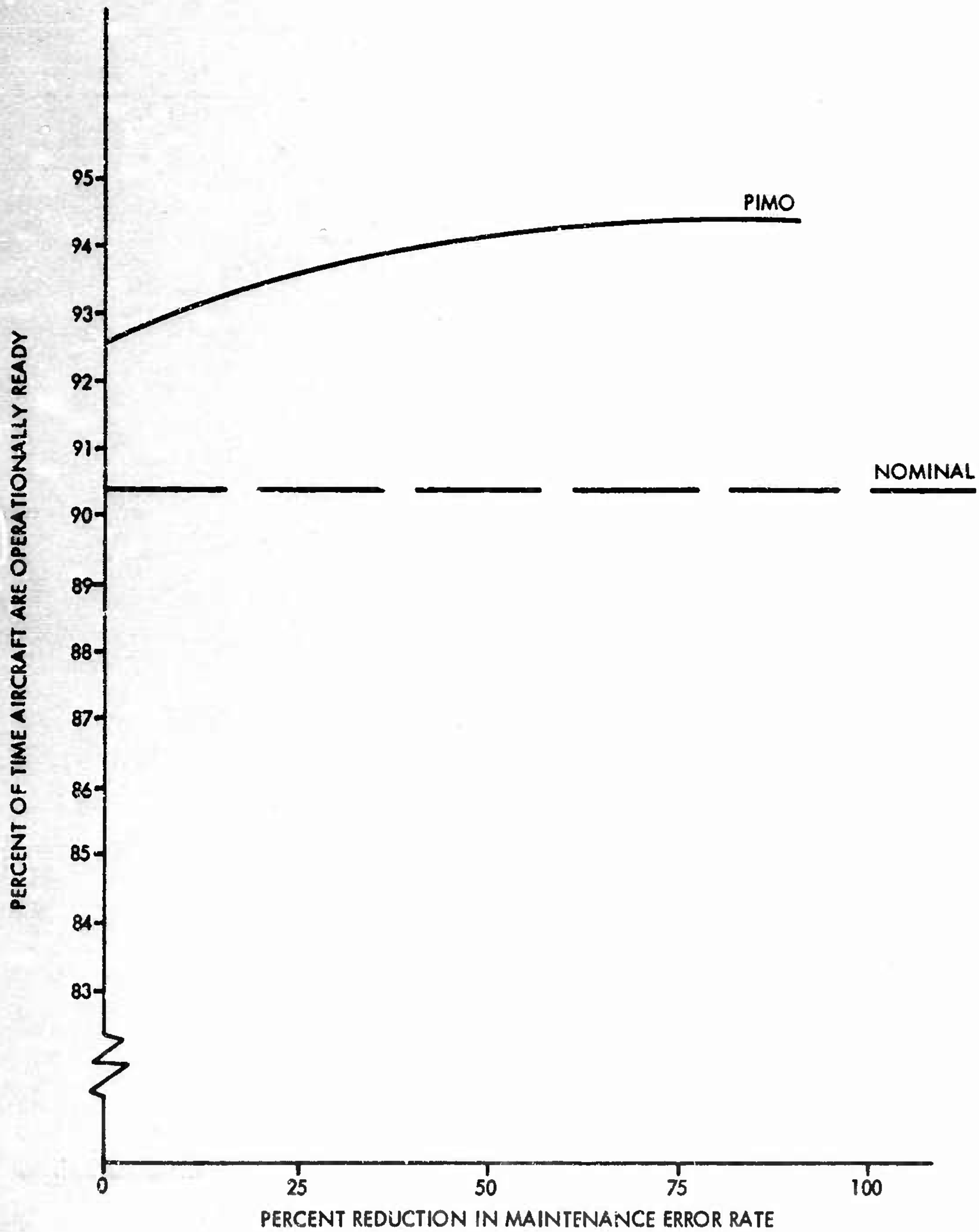

Figure 6-19 Effect of PIMO Upon Percent Operationally Ready Time

as a state other than that of preflight, postflight, scheduled, unscheduled maintenance or NORS. Inspection of this curve shows that when maintenance errors are reduced 50%, they were followed by a reduction in non-operational readiness state of 38%. By a 75% reduction in errors, the improvement in non-operational readiness has nearly reached its asymptote -- since for a 100% error reduction the improvement in reduction of non-operational readiness is 40%. It is important to realize that this improvement comes not so much from a reduction in error rate as it does from the fact that low skilled personnel have been included in the pool of available maintenance technicians. Use of people at this experience/training level means that there were less queues in maintenance, produced by the lack of maintenance personnel.

4. <u>Analysis of Maintenance Personnel Requirements</u>

Another tack taken with the AMES model was to reduce the maintenance personnel until the model showed a performance for the operational characteristics, using PIMO, equal to that of the nominal case. At this point, a conclusion could be made that if maintenance technicians did employ the PIMO formatted data the number of personnel could be reduced by some amount, with the operational characteristics equal to those currently in existence. This does not mean that one could hypothesize a personnel reduction across all areas or all skills, but rather only those which PIMO would effect. For example, personnel reduction would not apply to scheduled inspection, support shops, transistory aircraft personnel, or supervisory personnel. Figure 6-20 represents the upshot of the model runs using the number of mission delays as the criteria. It can be seen that if PIMO were to reduce the error rate by 50%, personnel could be reduced by 30% with no penalty being paid through generating more mission delays than are currently experienced. In a like fashion, when a 75% reduction in errors is hypothesized, a 36% reduction in personnel becomes possible. Finally, for a 100% reduction in errors, one could realize a 39% personnel reduction. Here again while a 100% reduction in errors was

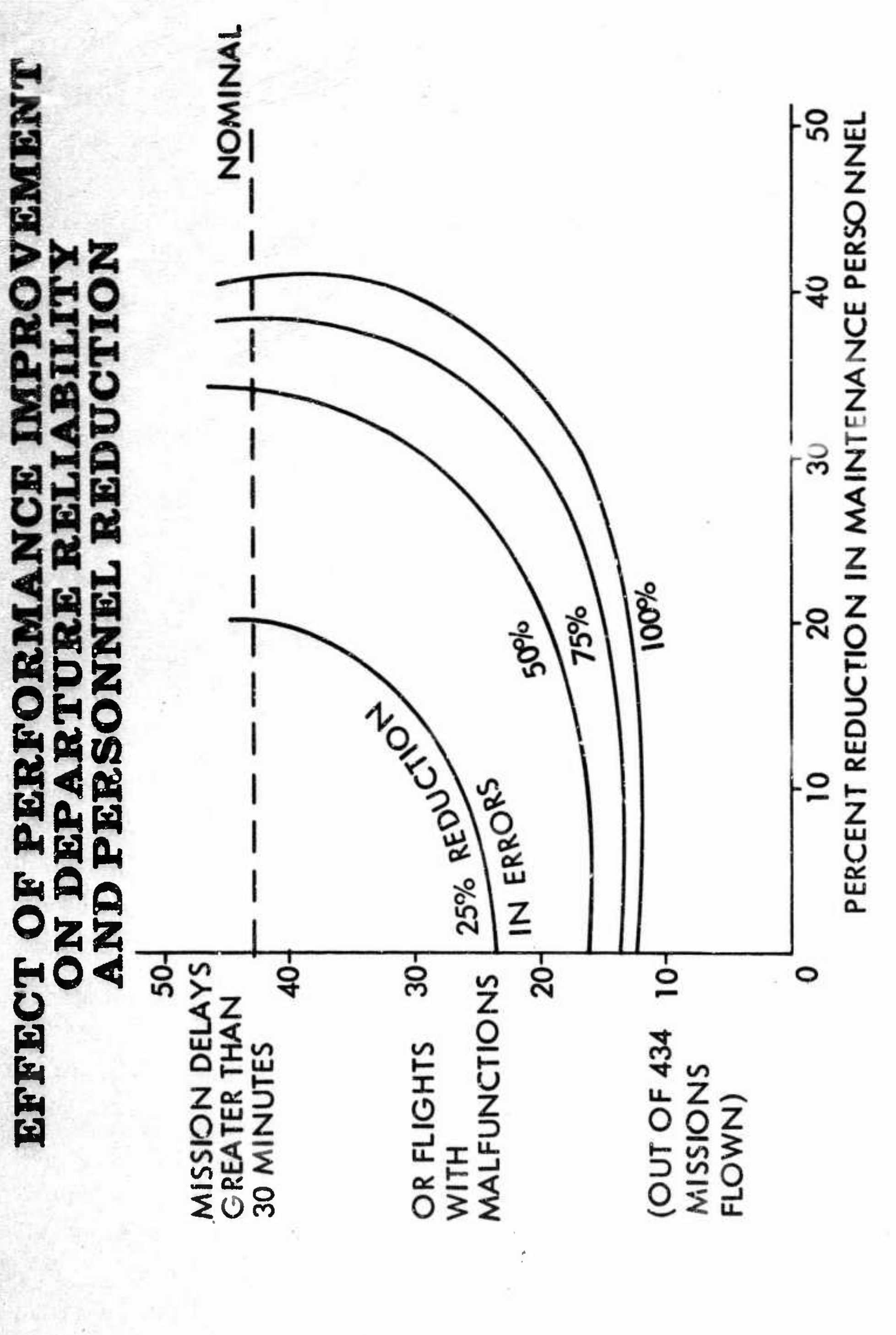

Figure 6-20 Effect of Performance Improvement on Departure Reliability and Personnel Reduction

observed in the field test it is unwise to expect that circumstance to continue in a real-life situation. Nonetheless, even with a 50% reduction in error approximately 1/3 of the personnel could be reduced with no increase in mission delays than are currently in effect. This has a dramatic impact on both over-all system life-cycle costs, and on the quality of maintenance possible in some locations of the world where complete maintenance staffing, as currently visualized, would not be possible.

Figure 6-21 shows a similar curve for the total aircraft hours in unscheduled maintenance. Here, one can see that the results are only slightly less favorable than from that curve which represents the effect on mission delays. Once again, if one were to hypothesize a 75% reduction in errors, the model run indicates that one could reduce personnel by 34% with no penalty of increase in total aircraft hours or unscheduled maintenance.

Finally, Figure 6-22 supports the results and conclusions drawn from the two previous curves. Again taking the 75% reduction in errors as a reasonable departure from the observed error reduction rate seen in the field test, the model indicates that a 37% reduction in personnel could be effected with no penalty.

The obvious conclusion to be drawn is that through the use of PIMO formatted job guides, a reduction both in staff and in maintenance errors could be realized. This would then reflect significant savings, both on the resources of personnel and parts stores. In addition, one can readily see that when aircraft are unavailable for mission assignment, -- due to maintenance requirements -- the costs for the aircraft system continue to soar, since flight crews are not productive.

These runs, while derived from simulation, do have validity and are in direct consonance with the results of the basic and the special study. This is not surprising, since the differences between a nominal case and the effect of PIMO on the parameters of study, were based on data

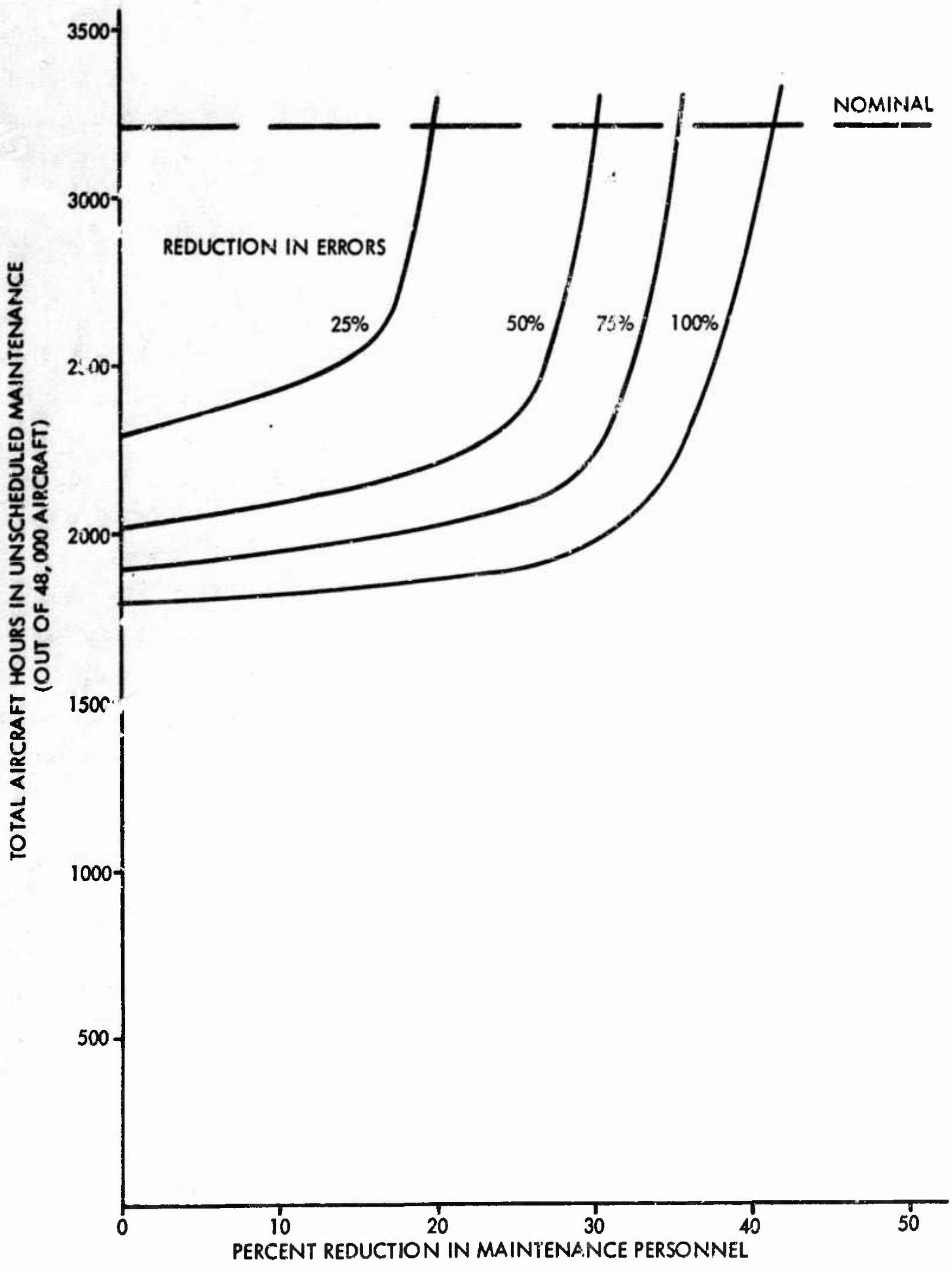

Figure 6-21. Effect of PIMO, With a Reduction of Personnel, Upon Aircraft Hours in Maintenance

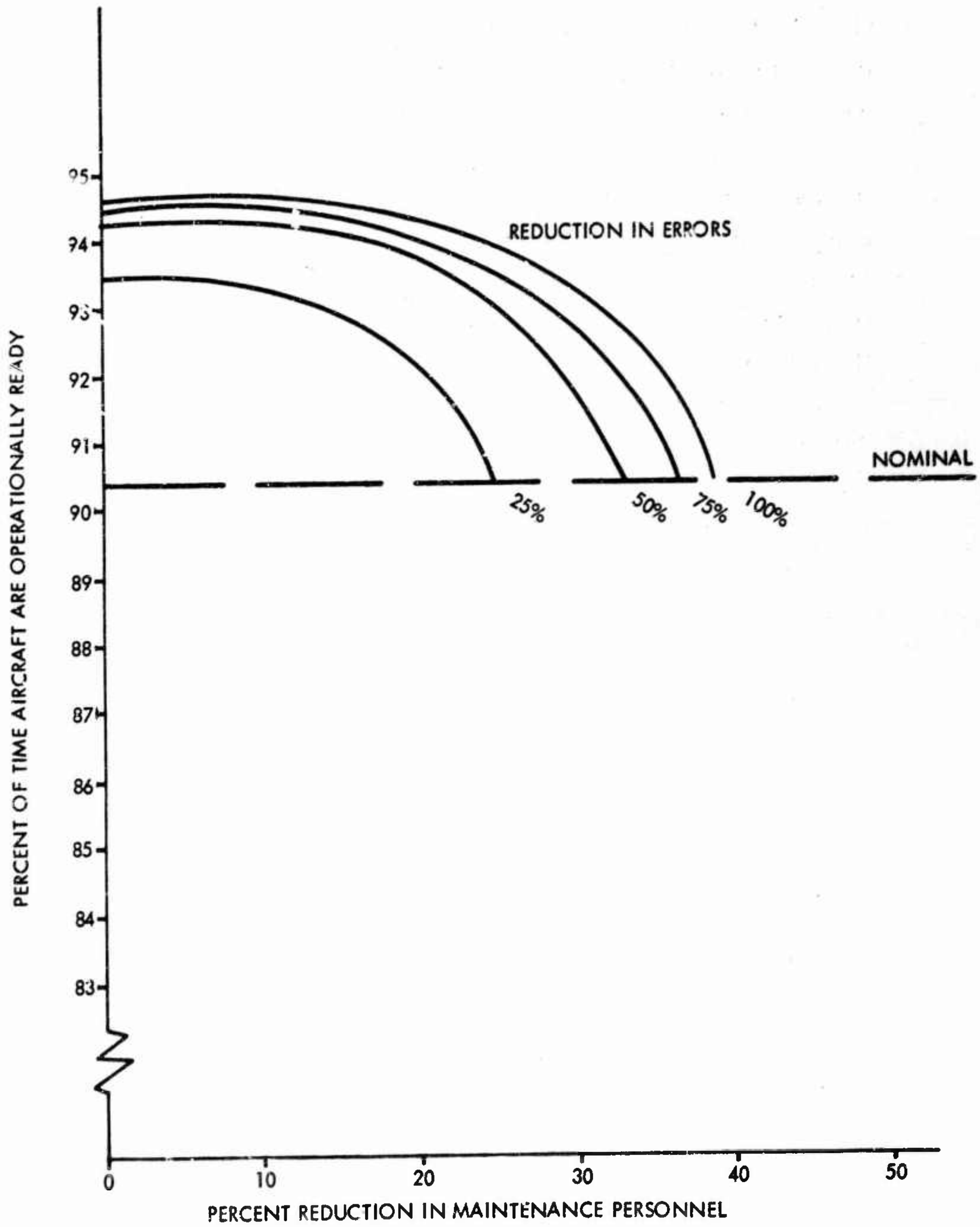

Figure 6-22. Effect of PIMO, With A Reduction of Personnel, Upon Percent Operationally Ready Time

taken from the field study. Since some of the earlier analyses have demonstrated that the mean performance times observed during the field test may be inaccurate and not reflect the long term expected benefits (because they include the early portions of the learning curve) it was decided to exercise the AMES model again. This time it was based on the performance times related to the toe of the learning curve as opposed to the over-all means. During the field tests, for example, it was generally found that it took longer to perform maintenance tasks using PIMO, than to perform the same task under SOP. Since the learning curves demonstrated that technicians -- through continued use of PIMO materials in the same job -- were able to significantly reduce their performance time, until these times approached those of skilled technicians using SOP, it was decided to use those values as the new data pool. If this hypothesis can be accepted -- that the expected long-run PIMO times are equal to, or less than, the current methods of operation -- then the results generated by the previous AMES model runs are conservative. For purposes of these later runs it was hypothesized that the long run PIMO time was equal to the current SOP times. In this later analysis, the nominal case remained identical to that described for the runs which were presented earlier.

Five model runs were made of the PIMO case, each at a different error rate, 0, 25, 50, 75, and 100% reduction in errors. The runs were conducted in such a way as to test only the effect upon the operational characteristics, and not the effects upon a personnel reduction.

The results of these model runs are presented in Figures 6-23, 6-24, and 6-25. In these figures, one will see the curves generated as a result of the second AMES run, as contrasted with the curve generated during the first run. These series of curves indicate that as inexperienced technicians become skilled in the use of PIMO and skilled in the maintenance of the aircraft, the benefits will increase significantly over those reported in the earlier study. In all cases, the new curve is found to be somewhat parallel to the original curve, but in the

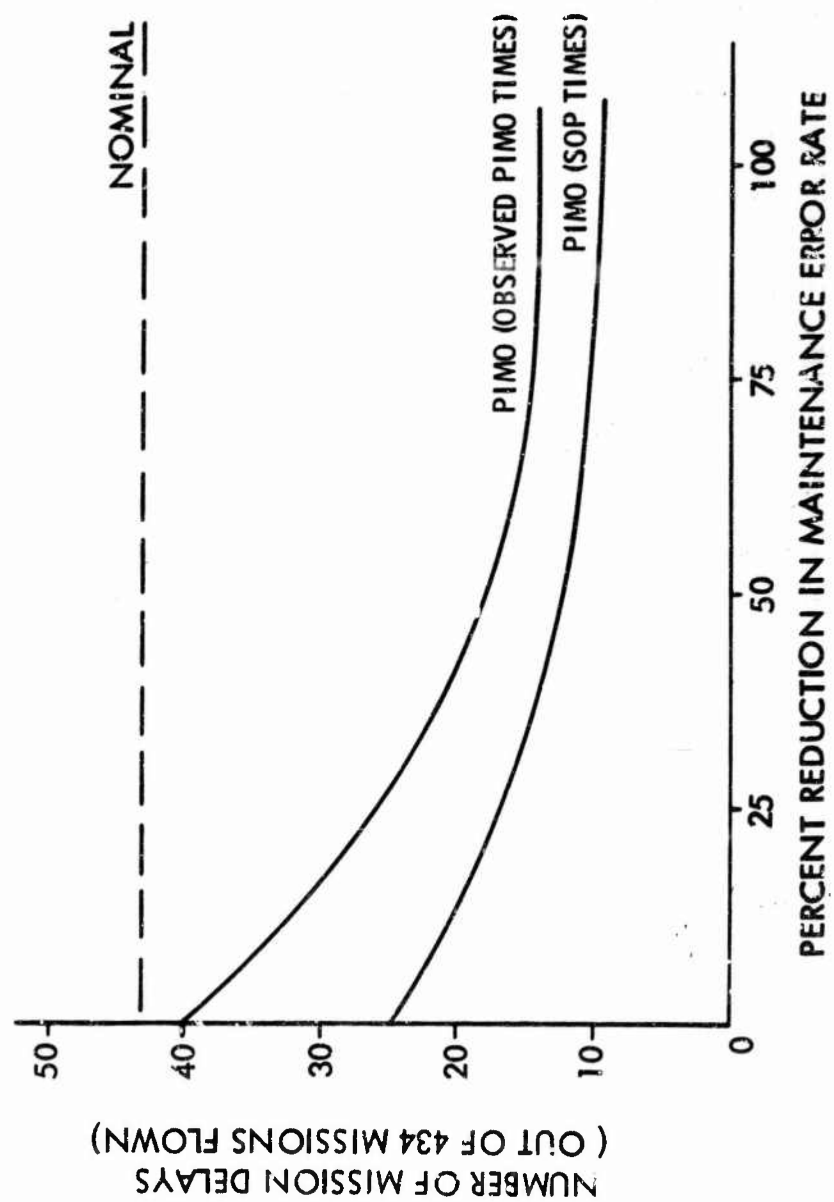

Figure 6-23. Model Run Curve

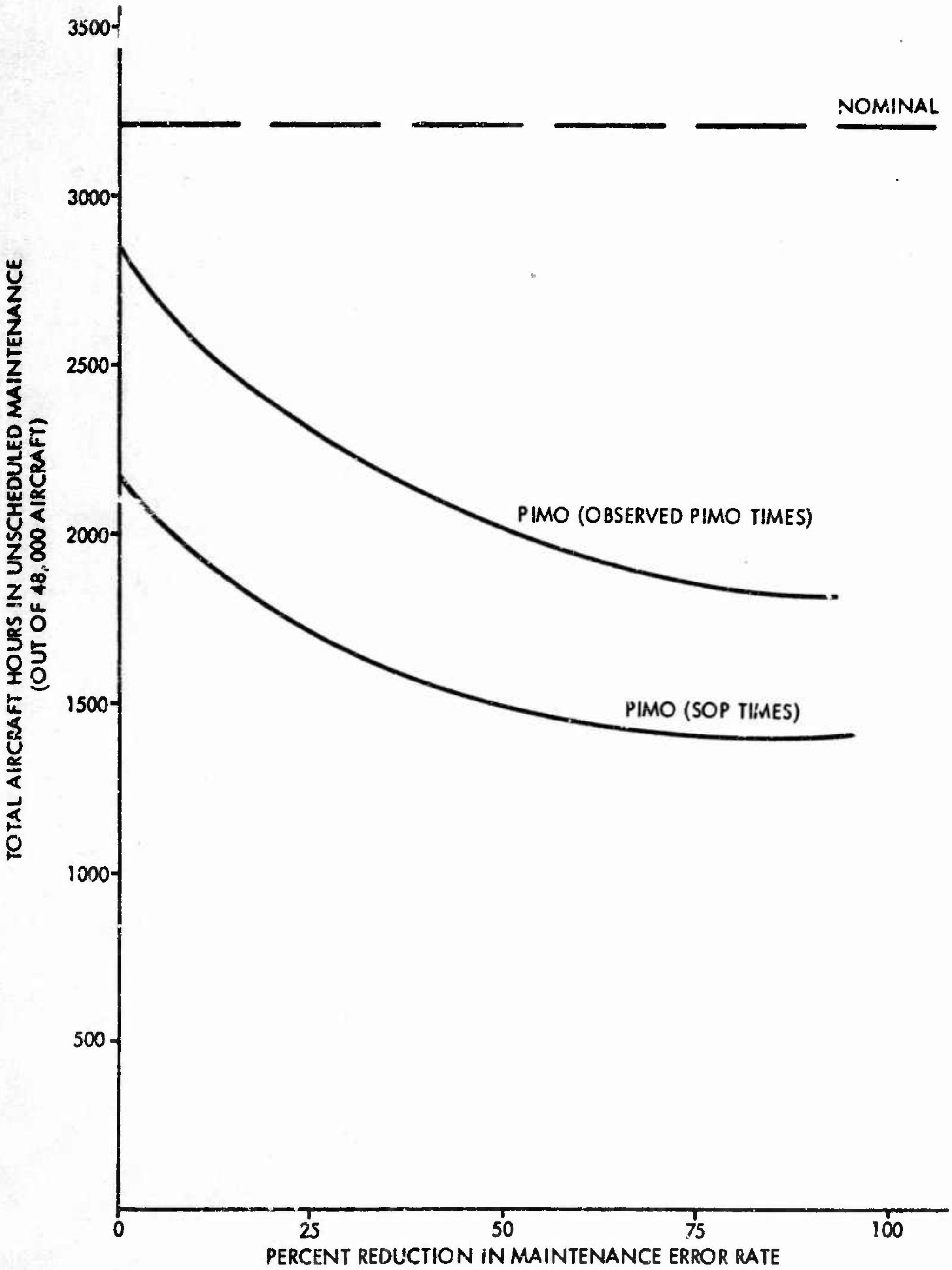

Figure 6-24. Model Run Curve

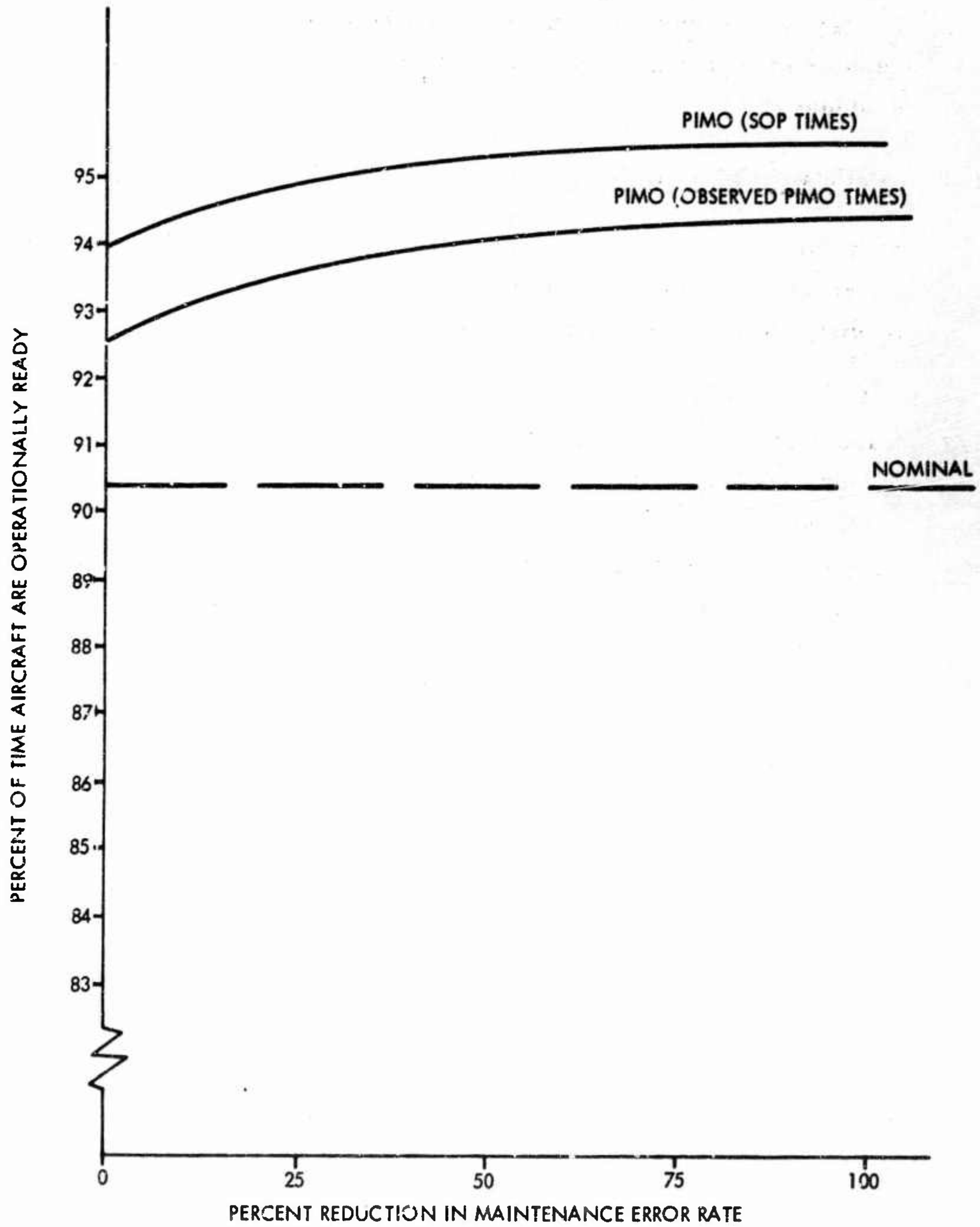

Figure 6-25. Model Run Curve

direction of greater effectiveness. The same conclusions drawn from the earlier set of curves can be applied to this set, but with the degree of systems-effectiveness enhancement shifted in the positive direction. Finally, one should be cautious about these particular sets of curves since they represent hypothesized values, as opposed to observed values.

F. SUMMARY CONCLUSIONS

Section IV of this volume listed five specific hypotheses that had been generated as a consequence of earlier studies. These hypotheses will be discussed and analyzed individually.

1. The originally intended criterion measure for this hypothesis was the mean performance time for all personnel with PIMO data and using the SOP. On the basis of the test, this hypothesis must be rejected. However, a major finding of the test was that inexperienced personnel can perform using PIMO data. Inexperienced personnel constitute a significant fraction of the total maintenance staff at any base. Effective use of these individuals is more significant to overall system efficiency than a 10% reduction in maintenance time. If the hypothesis is considered to cover inexperienced technicians only using PIMO data versus using the SOP, the hypothesis is accepted.

Also, if one uses system-wide maintenance time as the reference, the hypothesis can be accepted marginally since there is a decrease in an aircraft being out of service due to maintenance requirements.

2. The second hypothesis stated: PIMO data presented by the audio-visual mode would result in an additional 10% reduction in maintenance man-hours. Here, there are no data to support this hypothesis. In fact, it would seem that in most cases there were no statistical significances associated with the difference in performance times between audio-visual and booklet presentation mode. Therefore, in all scientific candor it must be concluded that this hypothesis was not supported.

3. The third hypothesis stated: a 45% reduction in maintenance errors would be possible when technicians used the PIMO Job Guide. This hypothesis can be accepted at the most stringent level of significance. This is true because there were no observed maintenance errors when the technicians were using the PIMO Job Guides. This represents not a 45%, but indeed a 100% reduction in maintenance errors.

4. The fourth hypothesis stated: for 80% of the maintenance tasks that might occur, a 3-level technician with PIMO could perform as well as a 5-level technician with standard USAF Technical Orders. Here again there is clear evidence in support for this hypothesis. In fact, the data tend to suggest that not 80%, but 100% of the maintenance tasks could be performed by 3-level technicians as well as, or better than, the 5-level technician with the standard USAF Technical Orders. This was brought out most dramatically in the special test, where the maintenance activities were contrasted directly between the use of PIMO and the use of the standard technical orders. It will be recalled, that in those cases where an inexperienced and naive technician was asked to perform maintenance with tech orders, in some cases he was unable to do so. Where he had had previous experience on the PIMO Job Guides -- and subsequently was asked to perform maintenance using the tech orders -- his level of experience was such that he was able to complete it with a minimum of errors.

5. The last hypothesis stated that a significant reduction in system-wide spares consumption would result. The empirical data to support this hypothesis would come from the TSA effectiveness study, which clearly indicated that there were indeed fewer troubleshooting errors committed with the TSA manuals. The AMES model tended to support this hypothesis through simulation rather than through empirical evidence. (Nonetheless, the reliability and validity of the AMES model is great enough to lead one to accept this hypothesis). The AMES model did state that there would be a significant reduction in maintenance errors as a consequence of PIMO, and it would seem logical to

extrapolate this to its orderly conclusion, which would say that since better maintenance was performed, fewer spares would be consumed.

More generally, the three immediate behavioral effects which were expected were realized. There were real and direct reductions in maintenance errors, at least an indirect reduction in maintenance time -- depending on what is used as a reference -- and clear evidence to support the hypothesis that the ability of apprentice technicians to perform specialized maintenance with use of PIMO is adequate.

SECTION VII

AIRCRAFT MAINTENANCE EFFECTIVE SIMULATION (AMES)

A. INTRODUCTION

It was recognized early in the PIMO Project that in order to make the benefits of PIMO meaningful they had to be expressed in terms of a given system. In this case, the C-141 aircraft was named as the test vehicle. In order for the value of the maintenance system to be fully demonstrated, it was necessary that this evaluation be couched in objective and quantified terms; therefore, a means was devised which would relate changes in maintenance performances to changes in the over-all C-141A system effectiveness. The means developed and tested was the AMES Model. AMES, an acronym for Aircraft Maintenance and Effectiveness Simulation, is a digital simulation model programmed for the IBM 7094. This model is a technique which allows the representation of a real system by means of a dynamic mathematical analog of that system. This analog is not identical to the real system but has a high enough degree of similarity to reflect the interactions and changes as might be expected by the real system.

This model was designed by Serendipity and employed to evaluate: 1) effectiveness of aircraft maintenance, and 2) a means of improving aircraft maintenance. It is generally accepted that the major advantage of any simulation model is the ability of that model to test hypotheses without having to exercise the real system. Obviously, an exercise of the real system would result in operating expenses which might far exceed the value to be gained by the results of that exercise. In fact, this very attribute of expense associated with exercise of a real system often tends to inhibit what might prove to be productive research. Nonetheless, any model is limited by the extent to which it responds as a fair representation of its real world system. One must be cautious not to exercise the model beyond the

constraints included during its development. Lastly, one should be cautious and use judgment in the evaluation of any of the results generated by a model run.

B. STRUCTURE OF AMES

1. Basic Logic

The AMES Model basically is a reflection of the system diagram in Figure 7-1. As illustrated, each of the functions are represented by subroutines which determine: 1) that the function can be initiated using available resources, 2) the time required to perform the function, and 3) the effect of maintenance errors on system effectiveness. Included also are supervisory routines which control the movement of aircraft through the function which monitors and maintains a resource level such as spares, personnel and AGE equipment and finally manages the necessary inputs such as mission demands. The basic structure of the model is logically consistent with observed C-141A operations.

2. Basic Operations

The model is so configured that it can accept a squadron of twenty aircraft simultaneously. Aircraft status such as operational ready state is determined from its apparent condition upon entering each function. Previously supplied input data to the model determines the personnel required to perform any given function on the system. The capacity for the model allows for a maximum of ten different types or skill levels to be identified. Delays in maintenance for a specific technical specialty may occur in a model run even though a lesser experienced personnel of the same specialty may be available. This is true only as long as the prestated assignment policy indicates that only the qualified technician is permitted to perform that maintenance action.

The model can accommodate up to twenty aircraft systems with each system having a maximum of twenty-nine components. Equipment

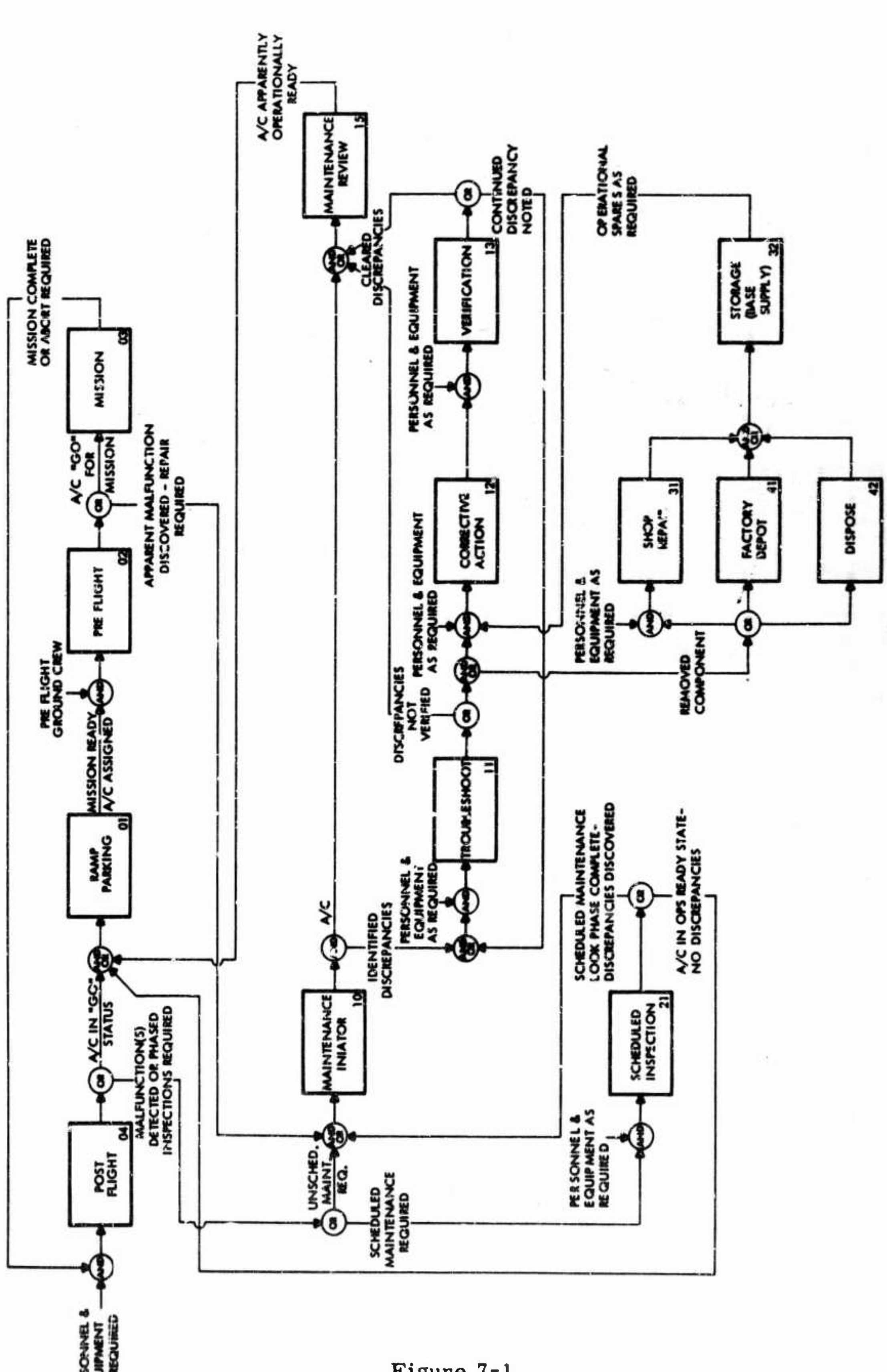
PERSONNEL & EQUIPMENT AS REQUIRED
POST FLIGHT 04
MALFUNCTION(S) DETECTED OR PHASED INSPECTIONS REQUIRED
A/C IN "GO" STATUS
RAMP PARKING 01
MISSION READY A/C ASSIGNED
PRE FLIGHT GROUND CREW
PRE FLIGHT 02
A/C "GO" FOR MISSION
APPARENT MALFUNCTION DISCOVERED - REPAIR REQUIRED
MISSION 03
MISSION COMPLETE OR ABORT REQUIRED
UNSCHED. MAINT. REQ.
SCHEDULED MAINTENANCE REQUIRED
MAINTENANCE INIATOR 10
A/C
IDENTIFIED DISCREPANCIES
PERSONNEL & EQUIPMENT AS REQUIRED
TROUBLESHOOT 11
DISCREPANCIES NOT VERIFIED
PERSONNEL & EQUIPMENT AS REQUIRED
CORRECTIVE ACTION 12
PERSONNEL & EQUIPMENT AS REQUIRED
VERIFICATION 13
CONTINUED DISCREPANCY NOTED
CLEARED DISCREPANCIES
MAINTENANCE REVIEW 15
A/C APPARENTLY OPERATIONALLY READY
PERSONNEL & EQUIPMENT AS REQUIRED
SCHEDULED INSPECTION 21
SCHEDULED MAINTENANCE LOOK PHASE COMPLETE - DISCREPANCIES DISCOVERED
A/C IN OPS READY STATE - NO DISCREPANCIES
REMOVED COMPONENT
PERSONNEL & EQUIPMENT AS REQUIRED
SHOP REPAIR 31
FACTORY DEPOT 41
DISPOSE 42
STORAGE (BASE SUPPLY) 32
OPERATIONAL SPARES AS REQUIRED

Figure 7-1

failures do occur randomly according to a distribution described for each component. Subsequent to their removal, components are traced through shop or depot repair and then on into base supply. Bad components resulting from erroneous maintenance are shown to enter base supply and do have an effect on the probability of removing a bad item for installation on an aircraft. Spares may be depleted resulting in the aircraft under consideration being placed in a NORS status.

Maintenance function errors are simulated by assigning two states for aircraft and components -- the actual state and the apparent state. Inherent failures are allowed to occur only in the mission function, or as the result of damage error in the repair function ("d" error). A failure or damage error establishes the actual state of a system and component as bad. It is then the duty of the air crew to identify the apparent state of the system. When this is accomplished without error, the actual and apparent state are congruent. Similar to equipment failures, personnel errors are said to occur randomly according to predescribed distributions.

It is possible to relate changes in maintenance function performance time and reliability to system performance through the simple expedient of following aircraft and aircraft components. An error in trouble-shooting may result in a mission abort and may ultimately require follow-up maintenance action. Thus, additional aircraft ground time is accumulated. Maintenance function variables have an indirect effect on the real world system in that they interact with such factors as resource availability, and personnel utilization. If, for example, function time is reduced, fewer delays are then incurred as a consequence of personnel unavailability. Moreover, improvements in function reliability reduce the demand for spare components which were erroneously removed, thereby reducing delays due to unavailability of parts. Since the AMES Model simulates the interactions of the availability of spares, personnel and AGE equipment, it reflects the effect of maintenance performance improvements.

C. AMES MODEL INPUT DATA

The AMES program currently accepts data which describes the aircraft in terms of its major subsystems and their principal components. Failure rates, repair policies, spares levels and data required for scheduled and unscheduled maintenance must be furnished to the program as well. In addition, data which specifies the required numbers and types of personnel is required as well as task performance times and personnel reliability. In this way, the set of input data established the pool of manpower, the number of shifts and the pool of maintenance equipment. External mission demands then act to drive the simulation.

Initially, the model was used to establish nominal values representative of C-141 aircraft operations currently in effect. The nominal case obviously did not reflect the effect of PIMO. This nominal case was derived from input gathered from existing Air Force published reports, raw Air Force maintenance and operational data (66-1 and F-1), field interviews and field observations. Once the nominal case was established, the AMES model was then used to determine the effect of PIMO on over-all systems operation and maintenance. This effect is measured or demonstrated quantitatively through its impact on the variance of the specific parameters mentioned earlier, i.e., mission readiness.

REFERENCES

1. Dixon, W. J., Massey, Jr., F. J., Introduction to Statistical Analysis, McGraw-Hill, New York, 1957.

2. Kerlinger, F. N., Foundations of Behavioral Research, Holt, Rinehart and Winston Inc., New York, 1966.

3. Lindquist, E. F., Design and Analysis of Experiments in Psychology and Education, Houghton and Mifflin Co., Boston, 1953.

4. Siegel, S., Non-Parametric Statistics for the Behavioral Sciences, McGraw-Hill, New York, 1956.

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13. ABSTRACT

This report describes the latest phase in the program to develop and evaluate PIMO (Presentation of Information for Maintenance and Operation); a job guide concept applied to maintenance. Between August 1968 and April 1969, a test was conducted at Charleston AFB, South Carolina, to determine the effectiveness of PIMO. Three immediate behavioral effects were expected: 1) reduction in maintenance time, 2) reduction in maintenance errors, and 3) allow usage of inexperienced technicians with no significant penalty. Experienced and inexperienced Air Force technicians performed maintenance on C-141A aircraft using PIMO Job Guides presented in audio-visual and booklet modes. Performance was measured in terms of time to perform and procedural errors. The performance was compared with the performance on the same jobs by a control group, i.e., experienced technicians performing in the normal manner. The following conclusions were drawn from the test results: 1) after initial learning trials, both experienced and inexperienced technicians using PIMO can perform error-free maintenance within the same time as experienced technicians performing in the normal manner, 2) inexperienced technicians perform as well as experienced technicians when both use PIMO, 3) there is no significant difference between audio-visual and booklet modes, 4) the users revealed an overwhelmingly positive reaction to PIMO, and 5) the performance improvements provide the capabilities to significantly improve system performance defined in terms of departure reliability, time-in-maintenance, and operational readiness. This report also presents a description of the recommended operational system, specifications and guidelines for PIMO format development, including troubleshooting.

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Aircraft Maintenance						
Troubleshooting Aids						
Field Test of Maintenance Aids						
Audio-visual Presentation, Maintenance Data						
Maintenance Dependency Charts, Preparation of						
PIMO, Programmed Information for Maintenance						
Technical Data, Reformatting of						
Technical Data, Specifications for						
Technical Orders, Comparison of (with PIMO)						
PIMO, Project Final Report						

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